Beard's Ventilation of Mines

THE VENTILATION OF MINES.

DESIGNED FOR USE IN SCHOOLS AND COLLEGES; AND FOR PRACTICAL MINING MEN IN THEIR STUDY OF THE SUBJECT.

BY

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Dedicated

TO THE MINERS OF IOWA,

AMONG WHOM THE AUTHOR HAS SPENT THE PAST THIRTEEN YEARS OF HIS LIFE.

PREFACE.

THE Ventilation of Mines is a subject to which all interested, miners and operators alike, should give the most earnest heed—*miners*, because upon the observance of its laws and principles depend their life and health; *operators*, because a thorough knowledge of the subject, followed by a faithful application of such knowledge in practice, cannot but result in a large saving of expense, ranging from fifty to seventy-five per cent.

It is a subject to which as yet American writers have contributed little. This is to be accounted for partly on account of the infancy, as it were, of the Mining Industry in America, as compared with its development in the mother country; but largely on account of the inordinate haste of Americans to see results. This haste is only too apparent in all of our industries, but in none is it more observable than in the mining; and one of its most deplorable results is to hinder and in many cases render wholly impracticable scientific observation. The American operator with but few exceptions adopts such appliances as first come to hand, or as suggest to him a saving in first cost; often not caring for, or taking the time necessary to, a thorough investigation as to the comparative operating

expenses of different appliances. Very often the machinery, fans, and other appliances brought into use have been purchased from some old mining plant and remodelled and repaired with true Yankee skill and ingenuity; but the type of construction is old and affords no opportunity for reliable investigation.

Such haste of Americans to see results and to make a fair showing of returns upon investment is therefore no help to the advancement of science; and were it not for their habits of close observation, their keen perception, their practical skill and ingenuity, they could not compete in the field of scientific research. The methods of Americans are, however, always practical, and herein is their value.

The field for scientific research among English mines has been larger. The mines as a rule are deeper and the mining plants present a more permanent aspect. English writers have contributed more to practical mining literature than any others. Foremost among those who have discussed the ventilation of mines are Mr. J. J. Atkinson and Mr. W. Fairley. There are probably many others worthy of note who have contributed to increase our fund of knowledge in this direction, but whose writings have not become so well known.

The French have furnished some good physicists, and their experiments and investigations of the laws controlling the motion of fluids, etc., have proved invaluable. The deductions of M. Murgue, relative to the "Equivalent Orifice," will be appreciated by mathematicians; but, as M. Murgue says himself, it is a mere fiction; and, we may add, does not rightly find its application in the ventilation of mines.

What is needed to-day is practical reasoning, supported by the results of true scientific observation. The investigator must possess a thorough knowledge and comprehension of the laws of physics: he must be a keen observer and a logical reasoner; above all, he must build his theories upon fact, never distorting the fact to suit a theory. Every law of physics acts continuously and as though no other law existed: the resultant condition is the algebraic sum of all the existing conditions. If any of these existing conditions are neglected, a true result is not obtained.

We see reports, from time to time, made upon so-called scientific investigations of results under varying conditions; giving, for example, the quantities of air yielded by a straight paddle-fan, discharging into a certain mine, making a certain number of revolutions per minute, and giving the diameter of the fan; but stating no breadth of blade, no temperature, or barometer, or hygrometric state of the atmosphere at the time of observation. Although the simple omission of the last-named item would be pardonable, as its effect is small, still, in careful observation, for scientific purposes, every affecting cause should be taken into account. The formulas of M. Murgue, relative to the fan, make no account of the width of the fan-blade; ignore, completely the questions of temperature, barometer, and hygrometric state; while it is a well-known fact that a fan is less powerful in light air than when working in a denser medium.

While it is the author's aim, in the following work, to base all his deductions upon mathematical principles, working out the same for the benefit and satisfaction of the student, it is, at the same time, his desire to

give to the practical miner a book of reference, the careful study of which will enable him to better understand the conditions with which he is surrounded and upon which his health and happiness so largely depend. As there is at present no American and probably no English work that is well adapted for use in schools and colleges, it is hoped that this little work may, to some extent, prepare the way for more extended and complete text-books upon a subject of such vast importance to the mining engineer.

By way of encouragement, the author would say to the student, where the reasonings or deductions leading up to certain conclusions may at times seem to be difficult, the study of the subject loses much of its formidable aspect if taken up one step at a time. It has been the aim throughout to present the subject step by step, and to so systematize the whole as to maintain a constant and healthful growth, and by this means to prepare the mind for a full and final conception of the whole. The processes of the calculus have been purposely excluded; some of the deductions engaging the study of the author for months at a time, as he has sought to disentangle them from the intricacies of the higher mathematics, with which they are almost inextricably associated.

To points wherein the author differs from other writers he has given the most careful and patient study; and submits his honest conclusions, by no means in a spirit of controversy, but with a desire to establish the truth and determine the laws that underlie and form the foundation of all mine-ventilation.

The author wishes to here acknowledge the courtesy and assistance of many friends, among whom may be

especially mentioned the State Mine Inspectors of Iowa, who have assisted, by every means in their power, to aid investigation, and whose mature judgment has more than once afforded valuable help.

J. T. B.

OTTUMWA, IOWA, December 16, 1893.

INTRODUCTION.

WHAT the author has endeavored to accomplish in the following pages is to make plain and simple to the practical mind the workings of the laws which animate and control the ventilating currents in mines. These laws are at times necessarily somewhat complex, because they express the relation between force and an expansive, fluid medium. The mechanics which formulates the expressions of force, as developed or transmitted by the rigid parts of machines, is simple, compared with the cubical and quadratic expressions involved in the discussions of force as applied to fluids. But, throughout, the endeavor has been made to express in simple, practical terms the results of mathematical calculation. While it is not expected that the general reader will care to investigate the methods of deduction, which require often a knowledge of algebra and the higher mathematics, yet these methods have, for the most part, been given in full, to demonstrate, for the benefit of the student, the exactness of the conclusions reached. This has seemed particularly essential, as some of the results obtained are different from those obtained by other writers.

It is believed some flagrant errors have crept into our mining formulæ, and some of the generally-accepted facts are based upon wrong hypotheses. For example, in relation to the action of fans, the idea seems to be

quite prevalent that the air-current partakes of the peripheral velocity of the fan-blade tips, and this becomes the initial velocity of the current. Although this is not the expressed idea of Murgue, yet even he transmutes the mechanical velocity of the fan-blade into an expression of head-of-air-column, which leads him seductively to the same error; as he continues, in the course of his reasoning, to treat the established velocity of the current as dependent alone upon the generative head-of-air-column; forgetting that the same head-of-air-column will produce a different velocity according to the conditions under which the current is moving. In other words, M. Murgue tries to assimilate the conditions of a current moving under a resisting pressure to the purely theoretical case of movement opposed by no such resistance. The velocity generated by a body falling through a certain height varies as the square root of that height; the velocity of the air in the mine varies as the square root of the pressure, other factors remaining the same; hence it is true that the height generative of any given velocity represents accurately the pressure animating such velocity where no resistance is opposed; but the analogy ceases when we introduce a foreign resistance opposing such velocity.

In discussing the flow of a current of air through a mine, we are dealing with a fluid medium moved or animated by a certain pressure. This pressure is created and maintained by the resistance ahead of the current, upon which it is directly dependent and not upon the power behind it. This is a very important distinction and must be borne in mind: it is merely stated here, but will be elucidated further on in the growth of the subject. It is aimed in this chapter to refer to certain

facts which are deduced later, in order to prepare the mind for a systematic study of the subject.

In making deductions relative to the fan, the method adopted in this work differs essentially from the method in general use, but seems to the author to be more simple and practical. It is based upon the centrifugal force developed by the weight of air revolved by the fan-blades. When a boy ties a string to his ball and swings it about his head, there is a tension, or pull upon the string, which represents the centrifugal force developed. Applying this principle to the fan, the air contained between the blades acts as the ball; only the ball pulls upon the string, while the air presses outward toward the periphery of the fan and creates a moving or ventilating pressure in the mine. The blades are always full and the air is revolved by them. We know the weight of this volume of air in revolution. The centrifugal force developed by this weight, considered as concentrated at the centre of gravity of the mass, is easily figured. The radial force thus determined is then applied, in our formulæ, to each particle of the air in question (the air contained between the blades), on the principle that

A force is measured by the velocity it can generate in a unit of mass in a unit of time.

Thus, by combining *mass of air* with *radial velocity*, we obtain an expression (mv) for the *radial-mass-motion*, or the *living force* imparted to the air contained between the blades. This contained air has then, by virtue of its revolution in the fan, been transformed into a radially-moving mass, whose living force (mv) is the power behind the current. If we wish to determine the pressure the fan would create when working into a closed

space—or, as we term it, the "*static*" pressure—we can divide the force developed (mv) by the surface pressed (the circumference of the fan multiplied by the width of blades). This is not, however, the most important determination to be made. It is more important to determine the *work* of this centrifugal force, as indicated by the expression mv^2, which is the force (mv) multiplied into its path (v), giving the work for one second of time. This will give us the *work* any given fan can accomplish; and taking into account the coefficient of efficiency (K), we place the effective work of the fan equal to the work to be accomplished in the mine $\left(\frac{ks}{a^2}Q^3\right)$. In this method we deal with no fiction, but with plain facts; and we believe the results obtained are simple and practical. *Work must always be placed against work.*

This brings us to another seeming error in our past formulæ. Mr. Fairley and others state that, "If we obtain a certain quantity of air by the action of a furnace, and another certain quantity by the action of a fan, or other means, their combined effect will be according to the square root of the sum of the squares of the quantities obtained separately; that is, according to the formula $Q = \sqrt{q^2 + q_1^2}$. Let us consider a moment. Suppose our furnace acting alone will pass a certain quantity of air q, and our fan acting alone will pass in the same mine, and under the same conditions, a quantity of air q_1. Now, the work the furnace will accomplish is denoted by the equation

$$u = \frac{ks}{a^2}q^3, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(a)}$$

and likewise, for the work of the fan, we write

$$u_1 = \frac{ks}{a^2} q_1^2. \quad \ldots \ldots \quad \text{(b)}$$

But the combined effect must be equal to the sum of these works, as, from the nature of the hypothesis, the work performed by the motors in the two instances remains unchanged; the same power being applied to the fan, and the temperature of the furnace remaining the same, in each case. Hence, adding equations (a) and (b), member to member, and denoting the sum of the works by U, we have

$$U = \frac{ks}{a^2}(q^2 + q_1^2). \quad \ldots \ldots \quad \text{(c)}$$

But we have

$$U = \frac{ks}{a^2} Q^2 \ldots \ldots \quad \text{(d)}$$

Hence, equating the values of U as given by equations (c) and (d), and reducing, we have, for the value of Q,

$$Q = \sqrt[2]{q^2 + q_1^2},$$

which is very essentially different from the expression in general use.

It is a fallacy, in discussing the mechanics of fluids, to suppose that if one motor is capable of yielding a unit of pressure p, and another motor will produce a unit of pressure p_1, working under the same conditions, their combined influence will yield a pressure equal to the sum of these respective pressures. This would be true in statics (i.e., when the airways are

closed and no movement results from the pressure); but in dynamics a change in pressure results in a change of velocity, and a consequent change in the resistance of the airway, which last again affects the pressure. Consequently the only basis of comparison is by means of the work. *Statics deals with pressure: dynamics deals with work.* It is of the utmost importance to keep this in mind constantly, in treating the subject of fluids.

The author would also draw particular attention to what is termed in the following pages the Potential factor of a mine, $\left(\frac{a}{\sqrt[3]{ks}}\right)$, and also its equivalent expression, $\left(\frac{Q}{\sqrt[3]{U}}\right)$, called the Potential factor of ventilation. The one expression gives the value of the potential in terms of the mine; the other gives the same value in terms of the current. The potential always shows the relation existing, in a certain mine, between the quantity of air passing and the cube root of the power necessary to pass such quantity. Thus, denoting the potential factor by X, we have

$$X = \frac{a}{\sqrt[3]{ks}};$$

also,

$$X = \frac{Q}{\sqrt[3]{U}}$$

A high potential always indicates a well-ventilated mine, as it shows a large quantity of air moved by a small power. It is obtained by increasing the area, by splitting the air-current; also by decreasing the value

of k to a minimum, by cleaning up the air-courses and avoiding sharp bends or angles as far as possible.

For the sake of illustration, let us compare two mines, the one having a high potential factor, as mine No. 4, with three splits of the air-current (see Table X); and mine No. 5, having but a single current of air. This latter case is not represented in the tables. At mine No. 4 a small twelve-foot fan, blades 30 inches wide, running at a speed of 60.8 revolutions per minute, is throwing 50,000 cubic feet of air, against a potential of 647.344. At mine No. 5, when there is but a single current, the potential will be low, viz., 188.502. Against this potential, a twenty-foot fan, blades 48 inches wide, running at a speed of 70.7 revolutions per minute, will only circulate 40,000 cubic feet of air. In this comparison we have the seeming anomaly of a twelve-foot fan, making only 60.8 revolutions per minute, and yielding 50,000 cubic feet of air, while our twenty-foot fan, making 70.7 revolutions per minute, is yielding but 40,000 cubic feet of air. Many casual observers would attribute this seeming discrepancy to the fan and say, "The fan is not doing its share of work." If, however, we glance for a moment at the work being performed in each case, we will see that the twenty-foot fan is accomplishing a work of 289.546 horse-power, while the twelve-foot fan is only performing a work of 13.963 horse-power. Hence the trouble is not in the fan, but in the method of ventilation employed in the mine.

We will now split the air travelling in mine No. 5, making two currents, and thereby raising the mine potential to 377.004. We find now that the power required is only one eighth of what it was previously, and our small twelve-foot fan, running at a speed of

79.7 revolutions per minute, will pass the same amount of air as was passed before by the twenty-foot fan. These results are tabulated below and serve to show the importance of adopting a good method of ventilation. The fans referred to in each case are the fans described in Table X of the Appendix.

	Mine No. 4.	Mine No. 5.	Mine No. 5.
Quantity passing...	50,000	40,000	40,000
Mine potential.....	647.344	188.502	377.004
No. of splits.......	3	1	2
Diameter of fan....	12 feet	20 feet	12 feet
Width of blade. ...	30 ins.	48 ins.	30 ins.
Revs. per minute...	60.8	70.7	79.7
H. P. expended....	13.963	289.546	36.193

Before closing this introductory chapter, which is intended as a preliminary sketch of the ground to be gone over, the author would state that the tables found in the Appendix have been carefully prepared and introduced, for the purpose of comparison, and to show at a glance results under varying conditions. It must not be supposed for a moment, however, that because any particular fan of the given dimensions, and working seemingly under similar conditions, does not throw the amount of air indicated in the table, the table is therefore wrong: there are many agencies of ventilation constantly at work in the pit, and these all have their influence upon the amount of air passing. To eliminate these secondary influences, and obtain a simple case of fan ventilation, is often a very difficult matter, requiring patience, care, and skill. The study of such secondary agencies of ventilation will be taken up in detail in the next chapter.

We are now prepared to enter upon a systematic and thorough study of our subject, beginning at the rudiments which the student must become a thorough master of before he can expect to grasp the more intricate problems with which the subject abounds. We must not be dazed or disheartened because of the complications which arise from the simultaneous action of so many agencies; but the student must bear in mind that in the physical world every law continues to act just as though no other law existed. Our study is throughout a study of those God-given laws which energize and control the universe.

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MINE-VENTILATION.

CHAPTER I.

CONDITIONS EXISTING IN MINES.

IT is essential, before entering upon a discussion of the methods and means of ventilation in mines, to obtain and hold in mind a clear idea of the elements or factors which enter into and form the component parts of our problem.

Ventilation.—First, we understand by the term "Ventilation," as applied to mines, the removing of the air contaminated and laden with the poisonous gases of the pit, and supplying in its place fresh air from the outside. To do this requires the maintaining of a constant current of air through the pit, and conducting such current by means of doors, stoppings, overcasts, etc., around the entire pit and particularly to the working faces, where it is most needed.

Gases.—The gases occurring in the pit and which contaminate the air are either formed in the mine, first and largely, by the slow combustion of coal in the gob and by mine fires; second, by the breathing of men and aminals, explosions of powder, burning of lamps, decay of timber, etc., giving rise for the most part to the formation of carbonic oxide or carbonic-acid gas; or,

as is the case with hydrogen carbide, commonly called Marsh-gas or Fire-damp, they exude from the body of the coal, as a product of earlier formation.

Gaseous and Fiery Mines—"Blowers."—Mines are said to be "Gaseous" when their workings emit natural gases. These gases may issue as "Blowers," under pressure, coming from some internal pocket, cavity, or chamber, more or less remote, where they have accumulated and from which they escape by some crack, crevice, or feeder which the drills may have pierced, or a settlement in the mine may have opened. When these natural gases are combustible or explosive, the mine is said to be a "Fiery" mine. In such mines the question of ventilation becomes a life-issue and the air-current a life-line. Upon the constant throb and pulse of the fan depends the life of the miner, as surely as upon the beat of his own heart. That this is not true in non-fiery mines renders such mines hardly less dangerous; because the consequent partial neglect of the question, or its being regarded as a purely secondary matter, renders the insidious poisoning from mine gases the more certain and deadly.

Kinds of Gases.—The gases most commonly occurring in mines are Carbonic-oxide gas (CO), Carbonic-acid gas (CO_2), Marsh-gas (CH_4), with traces of Hydrogen sulphide (H_2S) and Ammonia (NH_3).

"White Damp."—Carbonic-oxide gas (CO), commonly called "White Damp," is a combustible gas, burning with a pale blue flame. It is the same gas which is seen burning with a lambent flame over a freshly-fed anthracite fire. It is lighter than air, having a specific gravity of 0.967 and hence accumulates in the cavities of the roof and in the upper galleries or

headings. It is very poisonous, acting as a narcotic. It is colorless and, in the mine, odorless and therefore all the more dangerous, because its presence may escape the notice of the miner until too late for him to avoid its baneful effects. It has, however, a distinctly sweet taste in the mouth, and this often leads to its detection. Its effect is to cause a stupor or drowsiness, which is often followed by acute pains in the head, back, and limbs, accompanied with delirium. If the helpless and unconscious victim is not rescued soon, death is the result. The gas may be detected in the mine by its effect upon the flame of a lamp, causing it to burn with a small blue tip; and when present in any considerable quantity, the flame will reach upward in a long quivering taper. This is a warning, and the experienced miner will not tarry long in that place, as he knows the danger that lurks there. This gas is produced by the slow combustion of coal in the gob: it also results from mine fires, where the supply of air is scant; and from the decay of vegetable matter. explosion of powder, etc.

"**Black Damp.**"—Carbonic-acid gas (CO_2), commonly called "Black Damp," is an incombustible gas. It is heavier than air, having a specific gravity of 1.529, and hence it accumulates in the swamps and the low places of the mine. It is poisonous, acting as a narcotic, but is not as dangerous a gas as the one just described, because its presence is more readily detected, from the dimness of the lamps, and from their complete extinction when larger quantities of the gas are present. It is a colorless gas, and, in the mine, has very little odor, but produces a sweet taste in the mouth. Its effects are similar to those of carbonic-oxide gas,

creating also headache and nausea. It is produced by active combustion, burning of lamps, breathing of men and animals, decomposition and decay.

"**Fire-damp.**"—Hydrogen Carbide, or, as it is commonly called, "Marsh-gas," is a colorless, odorless, and tasteless gas. It constitutes the well-known "Fire damp" of the mines, and is largely responsible for the many colliery explosions constantly occurring. It burns with a slightly luminous flame: it is very light, having a specific gravity of only 0.559. Like hydrogen it is combustible, but will not support combustion when pure or unmixed with air or oxygen. This gas mixed with 3½ times its volume of air will not explode; but when the admixture of air equals 5½ times the volume of the gas a light explosion is rendered possible; when the gas is mixed with 9½ times its volume of air the explosive force of the mixture is the greatest; the presence of more air than this proportion weakens the explosive force of the mixture, and when the volume of the air equals 13 times the volume of the gas the explosion is again very weak. The Davy lamp is used for the detection of this gas and requires great caution and watchfulness to insure safety. It may be detected upon the lamp until the admixture of air has reached about 50 volumes. Marsh-gas is produced by the decay of vegetable matter under water, or where the air has been wholly excluded. It issues from coal-seams probably as a product of coal-formation, where vegetable matter has undergone decomposition through the agency of heat and pressure, with the entire exclusion of air.

Résumé.—We have now considered the more important of the mine gases. The remaining gases play

no appreciable part in the consideration of the subject of mine-ventilation. We have gone over in detail the natural condition of a pit; the vitiating influence and the poisonous effect of its exuding gases; and have referred to the general method in use for removing these gases, viz., by maintaining a constant current of air through the pit.

Agency of the Air-current.—The agency of the air-current is that of a sort of common carrier, by which the gases are conveyed out of the mine. This is accomplished through the action of the laws of "The Diffusion of Gases"; the obnoxious and poisonous gases mixing thoroughly with the air and diffusing completely, so as to be lost in the current, much the same as a drop of ink becomes lost in a glass of water. Our part of the problem then becomes the maintaining of a constant current of air into and through the entire pit; relying upon the working of natural forces for the diffusion and extraction of the gases.

Natural Agencies of Ventilation.—Before taking up the study of the applied forces, let us consider, for a moment, what natural aids or hindrances exist in the pit which become active forces, either aiding or opposing the circulation of the air. As previously stated, in the discussion of the flow of air-currents, we are dealing with an expansive, fluid medium, moved or animated by the element of pressure. Pressure is always the expression of some force; or obtains when a force is wholly or in part arrested. As we shall see in the next chapter, in the study of applied forces, pressure obtains as a ventilating force or agency whenever two columns of air in equilibrium have different temperatures. This will always be the case when a mine is ventilated

by means of two shafts, an upcast and a downcast shaft; as the air-current will naturally partake of the temperature of the pit through which it passes. Hence there exists, in every such pit, a natural agency of ventilation, either aiding or opposing the applied agencies in their work; and the influence of such natural agencies must not be overlooked in careful computations. This same natural force is developed in entries or airways, running to the rise or dip. Such rising or dipping entries act in the same manner as shafts, the vertical height through which they rise or fall being equivalent to the depth of the shaft. The action of such rise or dip may be either to accelerate or retard the circulation of the pit.

Suggestions.—On account of the above existing forces or agencies, we should always, if possible, place the fan, when forcing, over the shorter shaft, making the deeper shaft the upcast; for, as a rule, it will be the warmer of the two. For the same reason, we should always endeavor to have our intakes run to the dip and return to the rise. This will not, however, always be found possible or expedient. When we have a strongly-pitching vein, it will be better to take the air in at the lowest point and discharge it at the highest.

Natural Ventilation.—As a final and resulting condition, existing naturally in the mine, we have to consider "Natural" ventilation. As stated above, the air-current, or, more properly speaking, the ventilating current, is animated or moved through the element of pressure. When this animating pressure obtains in the pit from natural causes, it gives rise to natural ventilation. Natural ventilation is very unreliable and

changes, as regards the direction of the current, according to the relative temperatures of the outside and inside air.

Illustration.—Fig. I represents a vertical section through a drift, connecting with an air-shaft. In the winter season the air of the mine will be warmer than the outside air; and the shaft will be converted into an upcast shaft, the intake being through the slope. In the summer season the air in the shaft becomes chilled and heavier than the outside air and the course of the

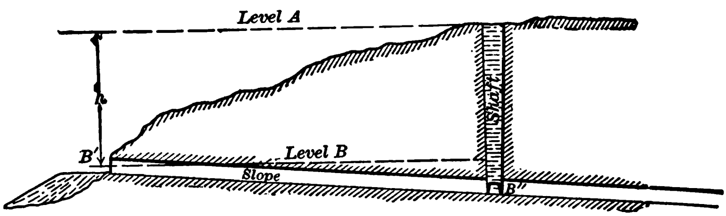


FIG. I.

current is reversed. Comparatively very few mines rely on this mode of ventilation, but all are subject to its influence and the quantity of air passing in every case is more or less affected by it, whatever the ventilating motor. It is important that this should be borne in mind in experimental investigation.

CHAPTER II.

FORCE AS APPLIED TO MINE-VENTILATION.

Prefatory.—Thus far we have taken a cursory view of the natural condition of the pit: we have looked over the ground very much as we would examine a new field before beginning operations relative to opening a mine, to acquaint ourselves beforehand with its existing conditions, the work to be done, and the natural aids and hindrances to the accomplishment of such work. Let us now, in like manner, continue to examine the material at hand; and to this end we will take up the study of force as applied to the movement of the air-current.

Force.—Force is an abstract idea: we cannot see force; we can only see its results. We raise a hammer and strike a blow that crushes a stone: we do not see the muscular force that animated the blow; but we see its effect, which is the demonstration of its power. We hold in our hand a ten-pound ball and we feel its weight, or we place it in the scale-pan and see it deflect the beam: this tangible and visible effect demonstrates to us the existence of a force of gravitation, but we do not see the force. We see the ship flying before the wind; we feel the strength of the hurricane; we see the devastation of the tornado: all these are evidences of a force behind the moving air which animates and propels. We may never answer the question, "What is force?"; but we can measure and compare

force with force. We have come to know the various transformations of force, and to measure it according to our standards. We have come to recognize pressure, velocity, heat, etc., as various tangible expressions of force; and these have become our standards of measure.

Measure of Force.—Force, as applied to air, has three measures, according to the conditions under which that force is acting. Let us suppose that we have a long conduit or air-passage, to one end of which we apply a constant force by means of a fan or other motor; three conditions may obtain, as follows:

1st. Closed conduit, giving pressure, but no motion or velocity.

2d. Long, open conduit, giving pressure and motion or velocity.

3d. Short, open conduit, giving no pressure, but velocity only.

Static Pressure.—In the first of the three cases just mentioned the force is converted wholly into pressure; and this pressure, called the "Static" pressure, is the measure of the force.

Dynamic Pressure.—In the second of these cases the force is converted partly into pressure, called the "Dynamic" pressure, and partly into velocity, the pressure and the velocity bearing an inverse ratio to each other; i.e., as the pressure increases, the velocity decreases and *vice versa*. The product of these two factors is the measure of the force in this case.

In the third and last case the force is wholly converted into velocity. If this velocity could be measured, it would be the measure of the force. This may, however, be called a theoretical case with respect to its application to mine-ventilation.

Moving Force or Ventilating Pressure.—The second of the three cases just referred to represents the condition which obtains in the mine. The moving force or pressure under which the air is moving is the power behind the current, and which animates the flow; it is the total pressure exerted against the sectional area of the airway. We term this total pressure, in this work, the "Ventilating" pressure, as it is the force necessary to move the current; or, in other words, the pressure necessary to produce ventilation. The unit of pressure, or the pressure upon one square foot of sectional area, we term the "Unit" of ventilating pressure. This unit of ventilating pressure is referred to by Atkinson, Fairley, and others, as the ventilating pressure, although Mr. Atkinson tacitly admits that such method is open to criticism. We represent the unit of ventilating pressure by the symbol p, and the ventilating pressure itself by the symbol $P = pa$.

Natural Pressure: How it Obtains.—Let us now investigate how the element of pressure obtains: first, from natural causes, and, second, by the application of artificial means, such as the fan or other motor; and afterward find expressions for such pressure, in terms of the means used.

Weight of Air.—That the air has weight, no one will deny. It may be shown in various ways, but in none more simply than by covering one end of a short tube or cylinder with a flexible diaphragm, and exhausting the air from the tube; the diaphragm will be pressed in by the pressure of the atmosphere upon it.

Barometric Pressure: Variations In.—The same pressure is also shown in the principle of the barometer, where the atmosphere supports a column of mercury

which varies in height according to the height of the observer above the level of the sea, and also according to the state of the atmosphere at the time of the observation. The barometer shows the pressure due to the weight of the atmosphere to be subject to a slight but regular diurnal variation, attaining a maximum about ten o'clock each morning and evening, and a minimum about four o'clock. Besides this regular diurnal variation, there is also shown to be a very irregular fluctuation in the atmospheric pressure, according to the presence of storm-centres, and according to the amount of moisture in the air, or, as we say, its hygrometric state; and other causes not necessary to mention here. But, disregarding these fluctuations for the present purpose, the pressure of the atmosphere at any level, or the barometric pressure, is produced by the weight of the air above that level, which fact plays a very important part in our discussion.

Expression for Weight of Air.—Our problem is to find an expression for the weight of a unit of volume of dry air at any temperature ($t°$), and under any barometric pressure (B''). Ganot, in his "Éléments de Physique," gives as the result of careful experiments the weight of 100 cubic inches of dry air at the temperature of 16° C. and a barometric pressure of 30″, to be 31 grains. This reduced gives, as the corresponding weight of one cubic foot of dry air, at a temperature of 0° F. and a single inch of barometer, 0.0028885 pounds avoirdupois, which agrees very closely with the results given by Atkinson. It has further been ascertained by careful experiment that air will expand $\frac{1}{459}$ of its volume for each degree of temperature of the Fahrenheit scale; and hence, taking the volume at 0° F. as one,

the volume at any temperature, as $t°$, will be $1 + \frac{t}{459}$; and the weights per cubic foot being inversely proportional to the volumes, we have

$$1 : 1 + \frac{t}{459} :: w : .0028885;$$

hence

$$w = \frac{459 \times .0028885}{459 + t},$$

or

$$w = \frac{1.325\cancel{8}\,3}{459 + t},$$

w being the weight of one cubic foot of dry air at $t°$ and $1''$ barom. Now as the weights of equal volumes are proportional to the barometric pressures, and for the sake of uniformity adopting Mr. Atkinson's figure, we have finally, for the weight of one cubic foot of dry air at a temperature of $t°$ and under a barometric pressure of B'',

$$w = \frac{1.3253 \times B}{459 + t}. \quad . \quad . \quad . \quad . \quad . \quad (I)$$

Effect of Temperature.—We come now to realize that the atmosphere about us has weight, and that this weight is a considerable pressure. We see from equation (I), that the weight of air is dependent upon the temperature, and that it varies inversely as the expression $459 + t$. Therefore, if two columns of air, as, for example, two shafts connected by the airways of a mine, have different temperatures, they will not maintain a static equilibrium, but a moving pressure will be

developed, incident to the two temperatures; and this surplus pressure is the moving or ventilating pressure spoken of previously.

Temperature, then, is directly responsible for natural pressure as it obtains in the mine.

"Head-of-air Column."—It has been found convenient to express the unit of ventilating pressure in terms of "Head-of-air Column," so called, representing the pressure, from whatever source, as though animated by the weight of such column of air. This head-of-air column is sometimes called the "Motive Column." It is an imaginary column of air of such height as to produce by its weight the pressure required. Denoting this head-of-air column by H, its value will be expressed by the equation

$$H = \frac{p(459 + t)}{1.3253 \times B}. \quad . \quad . \quad . \quad . \quad \text{(II)}$$

Caution.—In using this imaginary motive-column we must not for a moment suppose that the velocity of the air in the mine, due to this pressure represented, is the same as the velocity generated by a body falling through the height H. This is an error made by many, and we cannot be too careful in its avoidance. We would refer back to what has already been said in reference to this in the introductory chapter. Were there no resistance ahead of the current, or, in other words, were the power converted wholly into velocity, this supposition would be correct; but this is not the case. We are dealing in this instance with movement under pressure, or, as we say, a dynamic pressure. We assume the power applied to be sufficient to give

a certain quantity in a certain mine; that is to say, a certain velocity under a certain water-gauge or pressure. Now it is to the power that we look for the production of the velocity, whatever the opposing pressure. The pressure exists by virtue of the dynamic resistance; and the resistance depends not alone upon velocity, but upon another variable factor, viz., the rubbing surface of the airways. It is true that the head-of-air column or motive column is representative of a pressure, but such pressure is not analogous to the dynamic pressure of the air-current, for the reason that it is not governed by the same laws. We may have in two different mines, whose airways have the same sectional area, the same head-of-air column, as representative of the same ventilating pressure, and yet yielding different velocities and quantities, according as the rubbing surfaces in those two mines are different. It is the resistance that creates and maintains the dynamic pressure. This will be more readily seen in the study of the next chapter.

Head-of-air Column, or pressure as applied to the movement of fluids, and *Generative Height*, as applied to falling bodies, are not correlative terms.

Air-columns as Motors.—Let us refer again to Fig. I and assume two imaginary vertical columns of air, having their bases at B' and B'', respectively, and extending upward through the atmosphere. If we assume these imaginary air-columns to have each a base of one square foot area, the weight of air in each column above any level, as level A or level B, will be the unit of pressure at such point. Multiplying this unit of pressure by the sectional area of the airway, we obtain the total pressure upon the air at level B due to the

weight of the air above. These two imaginary columns of air, when connected below by airways, will be in equilibrium—*static equilibrium* if their weights are equal, when no current will result; and *dynamic equilibrium* if their weights are unequal and a current established. It is evident now that the weights of the two columns of air above level A will always be the same, being subject to the same temperature, and therefore may be ignored in ascertaining the differential pressure. Below this level they may be very different. This difference of temperature may result either from natural causes, as the heat of the mine, or from the application of artificial means, as the heat of a furnace. In either case a difference of pressure will result, and the air in the airways will be urged to move from the point of greater pressure to the point where the pressure is less, the moving force being the surplus of pressure which we term the ventilating pressure.

Pressure in Terms of Air-column.—The vertical height h between level A and level B, Fig. I, we will call the "Motive Height," because it is the height through which the motive force is exercised or developed, but this term must not be confounded with the term motive column, or head-of-air column previously referred to, as its significance is widely different. In ascertaining the differential or moving pressure, we are concerned only with the motive height.

Assume the following:

t = temperature of the outer air;
t_1 = avg. temp. of the air in the upcast shaft;
w = wt. of one cu. ft. of the outer air;
w_1 = " " " " " " " air in the upcast shaft;
B = height of the barometer in inches;

h = motive height;

a = area of cross-section of the airway.

Then

$(w - w_1)$ = the differential unit of weight;

$h(w - w_1)$ = " " " " pressure;

$ah(w - w_1) = P$ = the moving or ventilating pressure.

Referring to equation (I), we have

$$w = \frac{1.3253 \times B}{459 + t},$$

and

$$w_1 = \frac{1.3253 \times B}{459 + t_1}.$$

Hence

$$P = 1.3253 \times ahB\left(\frac{1}{459 + t} - \frac{1}{459 + t_1}\right). \quad \text{(III)}$$

When t_1 is greater than t, the value of P will be positive, which indicates an upcast current in the shaft; when t_1 is less than t, the value of P becomes negative, and then indicates a downcast current in the shaft. Equation (III) is true for all cases of mine-ventilation where only two temperatures are concerned in producing pressure. This is the case in a slope or drift-mine ventilated by a shaft, either by natural draught or by a furnace; also in a mine ventilated by means of two shafts, where either the downcast shaft is so shallow as to have practically the same temperature as the outer air, or the mouths of the two shafts are on the same level.

Primary Columns and Secondary Columns.—In all cases of natural ventilation the deeper shaft will determine the course of the current, by its relative tem-

perature; in all cases of furnace-ventilation, the furnace shaft will determine the course of the current, being the upcast. Therefore we may call these shafts the "Primary Columns" and the other shafts the "Secondary Columns." The temperature of the primary column is always represented by one temperature, while the secondary column may possess two separate and distinct temperatures, which cannot be averaged accurately. This gives rise to a case of mine-ventilation where three temperatures are concerned in producing the ventilating pressure.

Three Temperatures.—Fig. II illustrates a case of mine-ventilation (either natural or by a furnace), where three temperatures may be concerned.

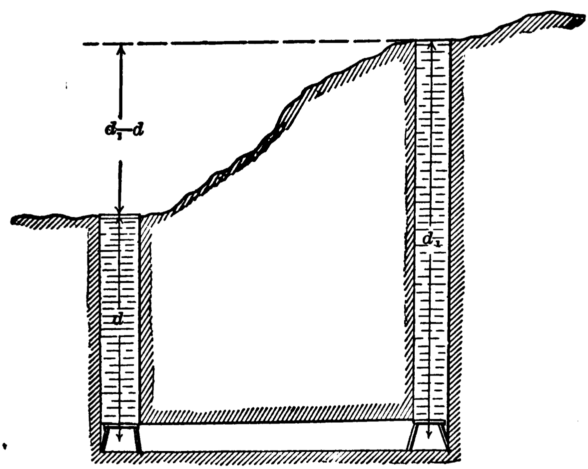


FIG. II.

Assume the following:

d_1 = depth of the primary or deeper shaft;
d = depth of the secondary shaft;

$(d_1 - d)$ = height of the outer effective column ;
t_1 = avg. temp. of the primary shaft ;
t_2 = avg. temp. of the secondary shaft ;
t = temp. of the outer air.

Then, by applying the same method used to obtain equation (III), we have

$$P = 1.3253 \times aB \left(\frac{d_1 - d}{459 + t} + \frac{d}{459 + t_2} - \frac{d_1}{459 + t_1} \right) . \text{(IV.)}$$

Equations (III) and (IV) will cover all cases of natural and furnace ventilation that will arise, and express in pounds avoirdupois the value of the elementary pressure due to heated air-columns.

Pressure in Terms of the Fan.—We will now determine the pressure due to the action of a fan. For the present we will content ourselves with determining the *static* pressure the fan is capable of yielding, i.e., the pressure the fan would give if working into a closed space. In all cases of compressive ventilation the pressure is created and maintained by the resistance of the mine, and its value is expressed in terms of the mine; and for this reason we delay its discussion till later. The method here adopted for determining the *static* pressure due to the action of the fan depends, as previously stated, upon the centrifugal force developed by the mechanical revolution of the air contained between the blades of the fan. This contained air possesses a certain weight, and this weight of air, compelled to revolve at a certain speed by virtue of its mechanical environment, will develop a certain centrifugal force or outward pressure.

Assume the following:

R = outer radius of the fan-blades;
R_1 = inner radius of the fan-blades;
b = breadth of blades;
n_1 = number of blades;
n = number of revolutions per minute;
R_2 = rad. of the cen. of grav. of one compartment;
v_2 = vel. of the cen. of grav. of one compartment;
v_1 = capacity between two consecutive blades;
W = wt. of air between two consecutive blades;
F = centrif. force of air in one compartment;
g = acceleration due to gravity (32.19);
p = unit of pressure;
t = temperature of the air;
B = barometric pressure in inches;

Now, since the unit of pressure is equal to the entire centrifugal force developed in all the compartments divided by the surface pressed, we write

$$p = \frac{n_1 F}{2\pi R b}. \quad \ldots \ldots \quad (1)$$

From mechanics, we have

$$F = \frac{W v_2^2}{g R_2}. \quad \ldots \ldots \quad (2)$$

But as v_2 is the velocity of the centre of gravity of one compartment, in feet per second, to correspond to the value of g, which is in feet per second, we have

$$v_2 = \frac{2\pi R_2 n}{60}, \quad \ldots \ldots \quad (3)$$

and, from mechanics, we have for the value of (R_2)

$$R_2 = \frac{2}{3}\,\frac{R^2 + RR_1 + R_1^2}{R + R_1}. \quad \ldots \quad (4)$$

We have also, from equation (I), remembering that $W = wv_1$,

$$W = \frac{1.3253 \times B}{459 + t} v_1. \quad . \quad . \quad . \quad . \quad (5)$$

Also, from geometry, we have

$$v_1 = \frac{\pi(R^2 - R_1^2)b}{n_1}. \quad . \quad . \quad . \quad . \quad (6)$$

Finally, by combining these six elementary equations and reducing, we have

$$p = 0.0001505 n_2 \frac{(R^2 - R_1^2)}{R} \times \frac{B}{459 + t}. \quad . \quad . \quad (\mathrm{V})$$

Equation (V) is applicable to all straight paddle-fans, and expresses, in pounds avoirdupois, the unit of *static* pressure the fan is capable of producing.

Other Motors.—Other air-motors are the steam-jet, waterfall, and various kinds of screw machines and volumetric appliances; but these are all unscientific, and are rapidly falling into disuse. They will not be discussed in this work.

Résumé.—We have now referred to pressure as developed by and expressed in terms of some motor, or, in other words, as the representative or agent of some animating, energizing force. The following chapter will consider opposing *pressure* as expressed in terms of the *resistance* of the mine.

CHAPTER III.

RESISTANCE OF THE MINE.

Resistance.—By *Resistance*, in general, is meant the force opposed to the movement of a body. It is always opposed to the moving force. Resistance to the movement of a fluid always creates a pressure throughout its mass, and this pressure is one of the factors by which we measure the moving force applied, as we shall see in the next chapter. In the case of the flow of air through the airways of a mine, the resistance (which is due to the rubbing of the air-current along the sides, roof, and floor of the airway) is applied all along the entire length of the current. For this reason the pressure arising therefrom decreases as we proceed along the airway and approach the discharge, where it is *nil.* From a consideration of this last fact we readily see that the ventilating pressure in a mine can never be greater than, but is always equal to, the resistance offered by the mine to the passing of the current. This resistance has been improperly called the "Drag" of the mine. There is no *drag* or *pull* known in the study of physical laws relating to fluids. Force or power is always *behind* the opposing resistance.

Kinds of Resistance.—It is well to notice that resistance is of two kinds. What we will call the "Static" resistance or the force to be overcome in order to create a circulating current, is much greater than the "Dynamic" resistance, or the force to be overcome in

maintaining such current after it is established. What will interest us the most in the study of the following pages is the *dynamic* resistance, and, as stated above, it is equal to the ventilating pressure *pa*.

How Varies.—The dynamic resistance varies theoretically as the extent of the rubbing surface and as the square of the velocity of the current. This is what we would naturally expect, because, if the velocity of the air-current be doubled, each particle of air strikes, in a unit of time, twice the amount of resistance, and each opposing blow is of twice the force; therefore the resistance is as the square of the velocity of the current; and as the number of resisting particles increases with the rubbing surface, the resistance will increase in the same ratio. We say the resistance varies *theoretically* as the extent of the rubbing surface, but, practically, the physical condition of the surface rubbed, as being rough or smooth, will vary the amount of the resistance; also, there can scarcely be a doubt but that the moisture condensed upon the sides and roof of the airway will act as a lubricant, and thereby reduce the resistance. Sharp bends or projecting angles in the airway are a serious hindrance to the passage of the air, and largely increase the resistance. But all of these are physical causes, affecting the coefficient of friction to be referred to hereafter; they in no way affect the working of the law by which resistance varies, and given above.

Static Resistance.—Static resistance cannot be formulated, as it depends upon too many arbitrary conditions and influences. When resistance is spoken of in this book it is dynamic resistance which is meant.

Dips and Rises.—An important factor affecting

the flow of the air-current, and which is often alluded to as a resistance (but it is not a resistance, properly speaking), is the occurrence in the entries or airways of dips or rises. The effect of such dips or rises, as aiding or retarding the flow of the air, will be discussed in this chapter; the question of such dips and rises affecting the proportionate flow at different velocities will come up for discussion in the chapter upon "Splitting the Air" (Chapter IX).

Effect upon the Current.—Considerable diversity of opinion has always existed among miners regarding the effect of a dip or a rise in the entry. It may be said with reason, however, that an intake working to the dip will assist ventilation, while an intake working to the rise will retard the same. This has been demonstrated a number of times: it will only be found to fail when the intake is warmer than the return, which is seldom. The reason is obvious, and has already been referred to in the discussion of "Natural Agencies of Ventilation" (Chapter I). If an air-course works to the dip, its return must show an equal rise in vertical height. This is evidently true whether the return parallels the air-course or not, except in some special cases—as, for example, a tunnel having two openings, or some similar instance of one direct current and no return. A mine in which the upcast shaft is located at a considerable distance from the downcast is an example of one direct current. An intake running to the dip and its return to the rise is but an illustration of natural ventilation in the large majority of cases, as the warmer air of the pit will naturally tend to rise, while the cool outer air likewise descends to take its place. On the other hand, an intake running to the

rise and its return to the dip presents a condition of things which is contrary to the natural; and a ventilating current compelled to travel in that direction will have this natural force or agency to overcome. The influence of dips and rises is a very potential one; its potentiality depending upon the vertical height of the dip or rise and the differential temperature of the intake and the return. It is, as we have said, another case of natural ventilation, in which the vertical height of the rise or dip corresponds to the motive height h of equation (II). The influence of dips and rises as a ventilating power must always be taken into account in nice calculations upon mining problems, especially in figuring upon the proportionment of air in different splits, and when the amount of the dip or rise is considerable.

Expression for Resistance.—In obtaining an expression for the resistance offered by a certain mine to its ventilating current we assume the following:

$R =$ dynamic resistance, opposed to any ventilating pressure $P = pa$;

$v =$ velocity of the air-current in feet per minute;

$s =$ rubbing surface of the entries or airways exposed to the current, expressed in square feet;

$k =$ unit of resistance, or the resistance, expressed in pounds (avoir.), offered by 1 sq. ft. of rubbing surface to air moving with a velocity of 1 ft. per minute.

Then we may write, from what has preceded,

$$R = ksv^2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{VI})$$

Pressure in Terms of the Mine.—From what has

preceded we have also seen that the ventilating pressure $P = pa$ is opposed and equal to the resistance R; hence we may also write

$$R = pa. \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{VII})$$

Then, by substituting this value of R in equation (VI), and solving with respect to p, we have

$$p = \frac{ksv^2}{a}. \quad . \quad . \quad . \quad . \quad . \quad (\text{VIII})$$

Coefficient of Resistance.—What we call the "Coefficient" of resistance is really the unit of resistance; it is expressed in our formulas by the symbol k. Solving equation (VIII) with respect to k, we have

$$k = \frac{pa}{sv^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{IX})$$

Value of.—On account of the various obstructions in the airways, and the varying physical conditions of the mine and airways, referred to in the early part of this chapter, no two mines will give exactly the same value for k. The value of k, as deduced by Mr. Atkinson, from a large number of experiments by others, has been very generally adopted; and we see no good reason for changing it, except it may be in some particular determination. For the purposes of general calculation and for the sake of uniformity, it should be always used. This value, as given by Mr. Atkinson, is

$$k = 0.0000000217.$$

The method of mining, mode of timbering, and other

details of working, which vary considerably according to the customs habitual in the district wherein the mine is located, may give upon investigation a coefficient more adapted to the mines in that district. Such a local value of k may be determined by taking careful observations in several typical mines of that district and then averaging the results, avoiding any that might seem to be unreliable on account of obstructed airways, small break-throughs, or other similar defects.

Practical Value of k.—The practical benefit arising from a known local value of k would be the ascertaining therefrom the necessary ventilating pressure for any proposed workings, in estimating and deciding upon size of fans and power of engines to be employed. It is a good factor to know; and after its value has been established in any district or class of workings, by careful observations in mines that are well kept, its subsequent application to other mines in that district will show the comparative condition of the air-courses in such mines.

Density as affecting Resistance.—The question is often asked, "Does a change in the density of the flowing air affect in any way the resistance or the power?" As far as the *resistance* offered by the mine to the passing current is concerned, the density of the flowing air does not change sufficiently to produce any appreciable effect. Likewise, also, the power is not appreciably affected as far as the mine is concerned—that is to say, the power required to pass a certain quantity of air per minute through that mine. But, on the other hand, the efficiency and power of the fan is very seriously affected by changes in the density of the air. This part of the subject, however, will be discussed later—

Chapter VIII. The causes which give rise to a change of density in the air of the pit are very numerous: first, the pressure of the pit due to the resistance (this pressure decreases all the way along the current, from the intake to the discharge, and affects the density correspondingly); second, the heat of the mine which is more potent in its effect; third, the absorption of aqueous vapor by the air in its passage through the pit; the density of the air being very slightly diminished by this absorption. The return current is always saturated, or carrying as much moisture as the temperature will permit, as is evidenced by its depositing this moisture upon the slightest fall in temperature, or what is commonly termed by the miners as the "sweating" of the pit. Air saturated with moisture at a temperature of 63° Fahr., which may be taken as the average temperature of the pit, will weigh one per cent lighter than dry air at the same temperature. In gaseous mines the presence of the pit gases will change the volume and the density of the air-current.

CHAPTER IV.

WORK.

Prefatory.—Before entering further upon the subjec- of "The Ventilation of Mines," let us complete the preliminary study of forces by refreshing our memories in respect to what is termed in mechanics "Work."

Definition of Work.—A force may exist in all its vigor and with unchanging constancy; and yet if that force does not move, or, in other words, if it is not exerted through a certain distance, it accomplishes no work. By *work* we understand a force exerted through a certain distance. The force and the distance through which it acts *together* become the measure of the work performed. In other words, a force multiplied by the path over which it has travelled represents the work of that force.

Unit of Work.—The adopted *unit of work* is the work performed by a pound avoirdupois falling through a vertical height of a foot, or that of a pound pressure moving through a distance of a foot. This unit is called in mechanics a "Foot-pound."

Power.—When we speak of *power*, we mean the ability to accomplish a certain work in a certain time. A boy may perform the work of a man if he is given time enough, or a man may do the work of ten men in a longer period of time.

Unit of Power.—The *unit of power* is a unit of work performed in a unit of time. The adopted unit of power

is the work performed by a pressure of a pound acting through a distance of a foot in precisely one minute of time. A unit of power will raise one pound avoirdupois through a vertical height of one foot in one minute of time.

Horse-power.—A *horse-power* is the power that will raise 33,000 pounds through a vertical height of one foot in one minute of time.

Work as a Measure of Power.—Work, then, is the measure of a power. The same power will always perform the same amount of work in the same time, though the work may differ in its kind. If we apply the same power to mines offering different resistances, the work performed in each case will be the same, because the power is the same; the velocities and the pressures may vary, according as the relative areas and lengths of the airways vary; but even under these changing conditions the same power will always accomplish the same amount of work.

Expression for Work.—Assume the following:

$U =$ work performed by a ventilating current;
$p =$ unit of pressure of the established current;
$v =$ veloc. in ft. per min. of the established current;
$a =$ sectional area of the airways.

Then from the definition of work we may write

$$U = pav. \qquad \text{(X)}$$

Substituting for p in equation (X) its value taken from equation (VIII), and reducing, we have

$$U = ksv^3. \qquad \text{(XI)}$$

Again, we know that the sectional area of an airway, multiplied by the velocity of the passing air (in feet per

minute), will give the quantity Q of air passing per minute, expressed in cubic feet, which gives the expression

$$Q = av. \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Substituting in equation (X) for av its value Q, we have

$$U = Qp. \quad . \quad . \quad . \quad . \quad . \quad (\mathrm{XII})$$

Again, referring to expression (1–XII), and solving with respect to v, we have

$$v = \frac{Q}{a}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Squaring both members of this equation and substituting the value of v^2 thus found in equation (VIII), we have

$$p = \frac{ks}{a^3}Q^2. \quad . \quad . \quad . \quad . \quad (2)$$

Finally, substituting this value of p in equation (XII), we have

$$U = \frac{ks}{a^3}Q^3. \quad . \quad . \quad . \quad (\mathrm{XIII})$$

CHAPTER V.

RESULTANT FACTORS OF VENTILATION.

VELOCITY, QUANTITY, ETC.

Résumé.—We have thus far considered—

1st. The natural conditions obtaining in a pit;

2d. Force as applied to the air-current;

3d. The resistance of the mine opposed to such force;

4th. Work as a measure of power.

While we have developed some important formulas incidentally, yet our study has been thus far largely preliminary.

Prefatory.—We will now consider, separately and in order, the various factors of ventilation that result from the application of force to overcome resistance, or of power to produce work.

Velocity.—We have seen that movement results from the application of pressure to air when such pressure is not wholly resisted. Such movement of the air in and through the airways is the velocity referred to. It is uniform, and proportionate to the cube root of the power and also to the square root of the ventilating pressure (under like conditions of rubbing surface in the airways). This is readily seen from equations (XVI) and (XVII), below.

Expressions for Velocity.—We have already seen, from equation (1–XIII) that

$$v = \frac{Q}{a} \quad . \; . \; . \; . \; . \; . \; . \text{(XIV)}$$

From equation (X) we have

$$v = \frac{U}{pa}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(XV)}$$

Again, solving equation (XI) with respect to v, we have

$$v = \sqrt[3]{\frac{U}{ks}}. \quad . \quad . \quad . \quad . \quad . \quad \text{(XVI)}$$

And, further solving equation (VIII) with respect to the same quantity, we have

$$v = \sqrt{\frac{pa}{ks}}. \quad . \quad . \quad . \quad . \quad . \quad \text{(XVII)}$$

Quantity.—The term "Quantity," as used in reference to mine-ventilation, means the number of cubic feet of air passing any given point in the airway per minute.

Expressions for Quantity.—We have seen before (eq. (1–XII)) that

$$Q = av. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(XVIII)}$$

Solving equation (XII) with respect to Q, we have

$$Q = \frac{U}{p}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(XIX)}$$

Solving equation (2–XIII) with respect to Q, we have

$$Q = \sqrt{\frac{pa^3}{ks}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(XX)}$$

Again, substituting in equation (XIX) for U its value taken from equation (XI), we have

$$Q = \frac{ksv^3}{p}. \quad . \quad . \quad . \quad . \quad . \quad \text{(XXI)}$$

Finally, solving equation (XIII) with respect to Q, we have

$$Q = \frac{a}{\sqrt[3]{ks}} \sqrt[3]{U}. \quad . \quad . \quad . \text{(XXII)}$$

Pressure.—We have seen before (eq. (2–XIII)), that

$$p = \frac{ks}{a^3} Q^2. \quad . \quad . \quad . \quad . \quad \text{(XXIII)}$$

Equation (VIII) represents another expression for pressure; it is repeated here to place these different expressions together:

$$p = \frac{ksv^2}{a}. \quad . \quad . \quad . \quad . \quad . \quad \text{(VIII)}$$

Combining equations (XII) and (XXII), and solving with respect to p, we have

$$p = \frac{\sqrt[3]{ks}}{a} \sqrt[3]{U^2}. \quad . \quad . \quad . \quad \text{(XXIV)}$$

Work.—(For the expressions of work, see Chapter IV.)

Potential Factor.—The term *Potential Factor*, as used in this work, is a term of special significance. It always has a value peculiar to the mine in question, and which represents for that particular mine the relation

which will subsist between the quantity of air passing and the cube root of the power necessary to pass such quantity. Referring again to equation (XXII), and dividing both members of the equation by the cube root of U, we have

$$\frac{Q}{\sqrt[3]{U}} = \frac{a}{\sqrt[3]{ks}}. \quad . \quad . \quad . \quad . \quad \text{(XXV)}$$

The first member of equation (XXV) expresses the value of the potential in terms of the quantity and the power: this expression we call the *potential factor of ventilation*. The second member of the equation expresses the value of the same potential in terms of the mine: we call it the *potential factor of the mine.*

Expression for the Potential Factor.—Assume

X = potential, referred to ventilation or to the mine.

Then from the definition of the potential factor we write

$$X = \frac{Q}{\sqrt[3]{U}}, \quad . \quad . \quad . \quad . \quad \text{(XXVI)}$$

and also

$$X = \frac{a}{\sqrt[3]{ks}}. \quad . \quad . \quad . \quad \text{(XXVII)}$$

Expressions in Terms of the Potential.—Substituting successively in equations (XIII), (XX), (XXII), (XXIII), and (XXIV) the symbol X for its value, as given by equation (XXVII), we obtain the following;

$$U = \frac{Q^3}{X^3}; \quad . \quad . \quad . \quad . \quad \text{(XXVIII)}$$

$$Q = \sqrt{X^2 p}; \quad . \quad . \quad . \quad . \quad \text{(XXIX)}$$

$$Q = X\sqrt[3]{U}; \quad . \quad . \quad . \quad . \quad \text{(XXX)}$$

$$p = \frac{Q^2}{X^2}; \quad . \quad . \quad . \quad . \quad . \quad \text{(XXXI)}$$

$$p = \frac{\sqrt[3]{U^2}}{X}. \quad . \quad . \quad . \quad . \quad \text{(XXXII)}$$

Quantity Due to Two Motors.—Assume the following:

q = the quantity due to any motor (as a fan running at a fixed speed) working alone;

q_1 = the quantity due to any other motive source (as another fan or a furnace) working alone;

Q = the quantity due to the simultaneous action of both motors.

Let u, u_1, and U represent the work performed in passing the quantities q, q_1, and Q, respectively. Then, referring to equation (XIII), we write, for the work performed in each of the three cases respectively,

$$u = \frac{ks}{a^2}q^3; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$u_1 = \frac{ks}{a^2}q_1^3; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$U = \frac{ks}{a^2}Q^3. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Now, when both of these motors are working simultaneously, or when any number of motors are working and throwing air into the same airways, each will perform its respective work, the same as when working

singly; for the work in each case depends solely upon the power applied, which we assume remains unchanged. Hence we write

$$U = u + u_1. \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Now by substituting in this last equation the several values of u, u_1, and U, as given by equations (1), (2), and (3), above, and dividing throughout by the common factor $\left(\frac{ks}{a^3}\right)$, we have

$$Q^3 = q^3 + q_1^3; \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and extracting the cube root of each member of the above equation we find, for the value of Q,

$$Q = \sqrt[3]{q^3 + q_1^3}. \quad . \quad . \quad . \quad \text{(XXXIII)}$$

Expression for Head-of-air Column in Terms of Temperature and Motive Height.—Referring to equation (III), we find an expression for ventilating pressure P, in terms of the temperatures of two air-columns, which may be the upcast and downcast shafts, respectively. Let us assume

t = average temperature of the downcast shaft;

t_1 = average temperature of the upcast shaft.

Then, dividing both members of equation (III), by a and substituting the value of p thus found in equation (II), and reducing, we have

$$H = h\left(\frac{t_1 - t}{459 + t_1}\right). \quad . \quad . \quad \text{(XXXIV)}$$

Expression for Horse-power.—As we have already seen, a single horse-power is equivalent to 33,000 foot-

pounds, or units of work; hence, indicating horse-power by the symbol *H. P.*, we have

$$H.P. = \frac{U}{33000}. \quad . \quad . \quad . \quad (XXXV)$$

Pressure in Terms of Water-gauge.—The *unit of ventilating pressure*, as indicated by inches of *water-gauge*, is calculated from the weight of a cubic foot of water. One cubic foot of water at a temperature of 62° F. weighs 62.355 pounds; and one inch of water-gauge will represent a pressure per square foot of $\frac{1}{12}$ of this, or, say, 5.2 pounds. Assume

i = inches of water-gauge.

Then we may write

$$p = 5.2i. \quad . \quad . \quad . \quad . \quad (XXXVI)$$

Pressure in Terms of Temperature and Motive Height.—Combining equations (II) and (XXXIV), and solving with respect to p, we have

$$p = h\frac{1.3253 \times B}{459 + t} \times \frac{t_1 - t}{459 + t_1}. \quad (XXXVII)$$

CHAPTER VI.

EXPRESSION FOR STRAIGHT-PADDLE FANS.

Prefatory.—In Chapter II we developed an expression for the static pressure due to the action of a fan; we are now prepared to formulate an expression for the *work* a straight-paddle fan is capable of performing, in terms of itself. Afterward, by equating this work and the work necessary to be performed in a mine in order to pass a certain quantity of air (Q) per minute (eq. XIII), we obtain an expression for the quantity of air a fan will yield per minute in terms of itself and the mine at which it is working. This is one of the most important determinations in the subject of mine-ventilation; the general method of procedure has been outlined in the introductory chapter, to which reference should now be made.

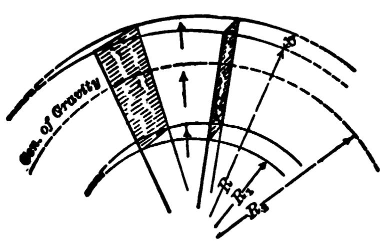


FIG. III.

Weight of Air in One Section of the Fan.—Let Fig. (III) represents one section of a straight-paddle fan,

showing the space between two consecutive blades. Assume as under equation (V). Combining equations (5–V), and (6–V), we have, for the weight of air in one section of the fan,

$$W = \frac{\pi(R^2 - R_1^2)b}{n_1} \times \frac{1.3253 \times B}{459 + t}. \quad . \quad . \quad (1)$$

Centrifugal Force of this Weight.—We have for the *centrifugal force* developed in one section of the fan, as given by equation (2–V),

$$F = \frac{Wv_2^2}{gR_2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Measure of this Centrifugal Force.—A force is measured by the velocity it can create in a unit of mass in one second of time; this measure f is called the acceleration due to the force F, and means *feet per second.* But our centrifugal force F acts upon a number of units of mass m; hence its measure is expressed by the equation

$$F = fm. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In this equation (3) m is the mass of the weight W; hence we may substitute for it its value $\left(\frac{W}{g}\right)$, and we have

$$F = f\frac{W}{g}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Combining equations (2) and (4), above, and solving with respect to f, we have

$$f = \frac{v_2^2}{R_2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Then, squaring both members of equation (3–V), and substituting the value of v_2^2 thus found in equation (5), above, and reducing, we have

$$f = 0.010966 \, R_2 \, n^2. \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Work of the Centrifugal Force per Second.—Equation (6), above, gives the value of f, the acceleration due to the force F, which we must remember acts radially. But when the force is uniformly accelerative, that is to say, when the force is constant and acts to increase the velocity of the mass by a constant quantity each unit of time, the space passed over during such unit of time will be equal to one half of the acceleration $\left(\frac{f}{2}\right)$; and, as we have seen from Chapter IV, the work of this force F during one second of time is equal to the force multiplied by this space over which it has passed in one second of time. Assume the following:

u = the work performed in one second by one section of the fan only;

U_1 = the total work performed in one second by all the sections of the fan;

U = the total effective work performed by the fan in one minute of time.

Then we have, from what has preceded,

$$u = F\frac{f}{2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Work of the Fan per Second.—For the entire work of the fan per second

$$U_1 = n_1 F \frac{f}{2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Combining equations (4), (6), and (8), above, and reducing, we have

$$U_1 = n_1 \frac{W}{g} 0.000060 12 R_2^2 n^4. \quad . \quad . \quad . \quad . \quad (9)$$

Now, substituting for W and R_2 their respective values, as taken from equations (1), above, and (4–V), and reducing, equation (9), above, becomes

$$U_1 = 0.000005 18 n^4 b R_2 (R^2 - R_1^2) \frac{B}{459 + t}. \quad (10)$$

Effective Work of the Fan per Minute.—Equation (10), above, gives the expended work of the fan for one second of time. Multiplying this work for one second by 60, to obtain the work for one minute, and introducing a coefficient K of efficiency (to be explained in Chapter VIII.—" Economic Discussion of the Fan"), we obtain for the effective work of the fan, for a minute of time, the following equation :

$$U = 0.000311 1 K n^4 b R_2 (R^2 - R_1^2) \frac{B}{459 + t}. \quad \text{(XXXVIII)}$$

Quantity yielded per Minute in Terms of the Fan and Mine. — Equation (XXXVIII) gives the entire effective work of the fan for one minute of time. This *effective* work of the fan must of necessity be equal to the work U performed in one minute by the ventilating current in the pit, and which is expressed by equation (XIII). Therefore, equating these values of U and solving with respect to Q, we have

$$Q = 0.06776 \sqrt[3]{\frac{a^2}{ks} \; K n^4 b R_2 (R^2 - R_1^2) \; \frac{B}{459 + t}}. \quad \text{(XXXIX)}$$

Equation (XXXIX) is the general equation for determining the yield of a straight-paddle fan, running at a fixed speed, at any given mine, the temperature and barometric pressure being also given. But care must be taken in its application that the effect of other agencies of ventilation are taken into account, such as upcast shafts heated by the natural heat of the mine, and dips or rises in the entries: these, as well as small break-throughs, obstructed airways, etc., etc., are sources very often productive of error.

Pressure yielded by a Fan.—We often hear the question asked, "What pressure or water-gauge will the fan give?" If the fan in question is working into a closed space, thereby creating a certain *static* pressure, the question is a proper one. But when the fan is throwing air into a certain mine, the pressure referred to is created by the resistance of the mine: it depends directly upon this resistance. The same fan, running at the same speed, but throwing air into another mine, will establish a different pressure, according to the resistance to be overcome. In any case of mine-ventilation, whether the motor is a fan or otherwise, the ventilating pressure may be found by applying equation (XXIII).

Horse-power of a Fan.—By combining equations (XXXV) and (XXXVIII), and solving with respect to $H.P.$, we have

$$H.P. = 0.00000000943 K n^4 b R (R^3 - R_1^3) \frac{B}{459 + t}. \qquad \text{(XL)}$$

CHAPTER VII.

ECONOMIC DISCUSSION OF THE FURNACE.

Prefatory.—It does not belong to the province of this work to discuss the comparative merits of different ventilating-machines; nor to remark upon their construction, only as such construction may interfere with the theoretical efficiency of the machine. Such economic construction relative to the furnace must provide—

First, a sufficient grate-area for the burning of the required amount of coal to produce the ventilating pressure P in that particular mine;

Second, a sufficient flue-area or airway over and around the fire, so as not to obstruct the flow of the quantity Q.

There are other essential points in furnace construction, but these are the only ones that affect the efficiency of the furnace.

Economic Grate-area.—By the *economic* grate-area is meant such an area of the grate of a furnace as will burn a given amount of coal in a given time and thereby give to the furnace a certain heating capacity, or, in other words, render the furnace capable of creating a temperature t_s in a current Q of mixed air and gases passing over and around it.

How Determined.—In order to determine the area of grate needed to cause a given rise of temperature

in a given current of mixed air and gases, we must ascertain the following.

First, the constituents, by weight, of the gaseous current and their respective specific heats, from which the power of the current to absorb heat is calculated;

Second, the heating power of a pound of coal, or, as we say, the number of thermal units contained therein;

Third, the square feet of grate-area required for the combustion of a given weight of coal per hour;

Fourth, the required rise in the temperature of the upcast current.

These data form the basis of the calculation. It is a practical problem in ventilation, and is by no means technical or theoretical. It requires no actual analysis of the gaseous current to determine its exact character for our purposes. What we must base our calculations upon is the worst possible state of the current with respect to gases and moisture, so that the results will be sufficiently large to meet any demand. Fortunately this extreme condition is determinable both with respect to gases and moisture. Having determined the several constituent gases and vapors, we multiply the weight of each of these by its respective specific heat, and take the sum of these products; multiply this sum by the required rise of temperature; finally, divide this last product by the thermal units contained in a pound of coal: the quotient thus obtained will be the weight of coal to be burned. The grate-area is then proportioned to this weight of coal, according to our experi ence and established rules.

Condition of Upcast Current.—As the calculations and reasonings incident to such an investigation are to some extent complicated, though by no means diffi-

cult, and as the general reader may not care to devote the time or patience necessary to a clear understanding of the details, we have tabulated in concise form the various factors entering the discussion, showing their final combination to produce the equation referred to above. This equation will be deduced in detail in the latter part of this chapter. The table referred to is Table II of the Appendix.

Dry Shafts.—We will now consider the practical application of equation (XLIV), which applies to dry shafts, and afterward explain its development in detail, taking up also, in the same connection, the data refer ring to wet shafts. In this equation ϕ represents the tension of aqueous vapor at the temperature t_4, its value being taken from Table III of the Appendix; t_4 is the temperature of the return current just previous to its entering the influence of the furnace; its value may be assumed to be as low as 70° F.: if in any instance it has a higher value than this, the furnace is thereby aided in its work; but we must assume such probable values as to make our calculation safe, and cover the case that will make the greatest demand upon the furnace. The value of t_6, the temperature of the lower end of the upcast, will depend upon the quantity of air to be furnished and the depth of the shaft.

Illustration.—To illustrate: Let us suppose we are about to open a mine, to be ventilated by a furnace, and we wish to provide for a capacity of, say, 500 tons of coal per day. We must figure upon, say, 240 men, including trappers and company men, and, say, 6 mules. If we give each man 100 cu. ft. of air per minute, and each mule 500 cu. ft. per minute, we shall require 27,000 cu. ft. per min. travelling; but, as we must provide against

every exigency,—gob-fires, poor stopings, obstructed air-courses, etc., etc.,—it will not be safe to estimate upon less than 30,000 cu. ft. of air per minute in circulation. In this problem the values assumed are taken as existing, adopted, or possible limiting values of the various factors of ventilation. We will suppose that the inlet and discharge openings are shafts of the same depth, and the seam of coal maintains a practical level throughout the pit.

Assume the following:

$h = 900$ ft. . . . . motive height.
$a = 50$ sq. ft. . . . . sec. area of airway.
$s = 120{,}000$ sq. ft. . . . rubbing surf. of airway.
$Q = 30{,}000$ cu. ft. . . . . at temp. t_3.
$t_2 = 32°$ F. . . . . avg. temp. of downcast.
$t_3 = 60°$ F. temp. of air where quant. is taken.
$t_4 = 70°$ F. temp. of air before reaching furn.
$t_5 =$ (?). . . . temp. of air at bottom of upcast.
$t_1 =$ (?). . . . . avg. temp. of upcast.
$B = 30''$. . . . . height of barom.
$s_1 = 28{,}800$ sq. ft. . . . . . . cooling surf. of shaft.
(Size of air-shaft, $8' \times 8'$.)
$k_1 = 0.5$. . . . . (relative) coef. of cooling.
$C =$ (?). . . . . pounds of coal burned per h.
$G = 1/10\ C$. . . . . grate-area of furn.

First determination: The first step in our problem is to determine the unit of ventilating pressure that will circulate the given quantity of air (30,000 cu. ft.) per minute, against the potential$\left(\dfrac{a}{\sqrt[3]{ks}}\right)$ 363.432. Referring to (equation XXXI), and substituting therein the above

numerical values, which we have assumed, and reducing, we have

$$p = 18.748 \text{ lbs.}$$

Second determination: The next step is to determine the average temperature t_1 of the upcast shaft which will produce the above unit of pressure. By substituting in equation (XXXVII) the above assumed values and the value of p just found, and solving with respect to t_1, remembering that t_2, the temperature of the downcast shaft, is the same as t, the temperature of the outside air, in this case, we find, after reducing,

$$t_1 = 202° \text{ Fahr.}$$

Third determination: The next step is to determine the necessary temperature of the bottom of the upcast shaft in order to produce the *average* temperature just determined above. By substituting in equation (XLVI), hereinafter deduced, the numerical values thus far assumed and determined, and reducing, we find

$$t_3 = 327° \text{ Fahr.}$$

Fourth determination: The final step in our problem is to determine the weight of coal that we must burn per hour upon the grate in order to produce the required rise in the temperature of the air-current. We have assumed the temperature t_4 of the air just previous to its entering the influence of the furnace to be 70° Fahr., while the required temperature after

passing the furnace we found must be 327°. This requires a rise in temperature due to the heat of the furnace of 257°. Now, referring to equation (XLIV) hereinafter deduced, and substituting therein the above numerical values, assumed and determined (taking the value of ϕ, for a temperature of 70° F., from Table III of the Appendix), and reducing, we find

$$C = 648 \text{ lbs.}$$

Knowing the weight of coal to be burned per hour in pounds, it is usual to assume one tenth of this weight as the area in square feet of the grate best adapted for the economic combustion of such amount of coal. Hence in this case we find

$$G = 65 \text{ sq. ft.}$$

Wet Shafts.—When the shaft is wet there will be an additional amount of coal necessary, beyond the amount required for heating the current, to evaporate the moisture of the shaft and raise the temperature of the vapor thus formed to the temperature of the current. Continuing the above illustration, which refers only to a dry shaft, let us now assume the same shaft to be making, say, four barrels of water per hour, or about 1000 pounds. Assuming the average temperature of evaporation t_v to be 126° F., and making the necessary substitutions in equation (XLV) and reducing, we find, for the additional amount of coal necessary on account of the wet condition of the shaft,

$$C = 80 \text{ lbs. (extra).}$$

Adding this to the amount of coal determined previously in the case of the dry shaft, we obtain for the total amount of coal required to be burned per hour, in this case, 728 pounds, which gives for the grate-area required

$$G = 73 \text{ sq. ft.}$$

Suggestions.—The furnace should always be built with airways or coolers above and on each side. The sectional area of such airways should not be less than the sectional area of the entries.

Relative Quantities.—The quantity of air Q_6 will be larger than the original quantity Q, owing to a rise of temperature from t_1 to t_6; the relation between these volumes or quantities being expressed by the proportion

$$Q : Q_6 :: 459 + t_1 : 459 + t_6;$$

whence we have

$$Q_6 = \frac{459 + t_6}{459 + t_1} Q, \quad . \quad . \quad . \quad . \quad \text{(XLI)}$$

in which Q and Q_6 are the quantities or volumes of air at the temperatures t_1 and t_6, respectively. From this equation we see that the volume of the current may be increased from 30% to 50% by the heat of the furnace.

Suggestions.—The increase of quantity referred to above is usually compensated for by a corresponding increase in velocity passing the furnace. Hence, if the pit is free from large gas feeders, it will be sufficient to provide a sectional area passing the furnace equal to the area of the entries. Coal for supplying the furnace

should be stored in cuts, in the rib made for the purpose, and not, as is often done, deposited in the airway, in front of the furnace, or, worse still, left in the car, standing in the air-course till needed. The loaded car should be switched into the cut in the rib and the coal used from it as needed, to save handling the coal twice.

We have thus far illustrated the practical application of the formulas; the remainder of the chapter will be devoted to explaining their development in detail, for the benefit of the student, and may be passed over, if so desired, by the general reader.

Thermal Unit.—The unit upon which all calculations are based, in investigations relative to the heating power of coal, is called the "Thermal" unit. It is the amount of heat absorbed in raising one pound of water one degree in temperature.

French Unit—American Unit.—The French use a unit referred to the Centigrade scale, and this unit contains more heat than our American unit, which is referred to the Fahrenheit scale.. The ratio between these two units is expressed by the fraction $\frac{9}{5}$.

Calorics of Coals.—Different coals possess different calorific powers, and hence contain a greater or less number of thermal units to the pound. Experience has placed the calorific value of bituminous coal, however, at 8000 thermal units to the pound of coal in the French system, or 14,400 units in the American system. In common practice bituminous coal is assumed to contain 14,000 American thermal units. These units are often spoken of as the *calorics* of the coal: they represent the amount of heat *that* coal is capable of giving out when burned.

Calorific Capacity.—Different solids, such as iron, copper, tin, etc., each absorb a different quantity of heat for a rise of one degree in their temperature. Different liquids, such as water, oil, etc., absorb likewise different quantities of heat for the same rise of temperature. So also different gases, including air, each absorb different quantities of heat for a rise of one degree in their temperature.

Specific Heat—The amount of heat thus absorbed by one pound of any solid, liquid, or gas, during a rise of one degree of its temperature, as compared with the amount of heat absorbed by one pound of *water* during a like rise in temperature, is called the "Specific Heat" of that solid, liquid, or gas. As the specific gravity of any substance is the ratio between the weight of such a substance and the weight of a like volume of water at a standard temperature, so also the *specific heat* of any substance—solid, liquid, or gas—is the ratio between the quantity of heat such substance absorbs during a certain rise in its temperature, and the quantity of heat absorbed by an equal weight of water during an equal rise in temperature.

Specific Heat expresses Thermal Units.—Now the amount of heat absorbed by one pound of water during a rise in its temperature of one degree Fahrenheit is adopted as our thermal unit. Hence it follows that the specific heat of any substance, solid, liquid, or gas, referred to water as unity, will express at the same time the number of thermal units required to raise one pound of that substance one degree Fahrenheit.

General Expression for Weight of Coal.—If, now, we multiply the specific heat of the substance (which we have just seen is equal to the number of thermal

units required to raise one pound of the substance one degree) by the weight W of the substance and then by its rise in temperature, say $t_5 - t_4$, we shall obtain the thermal units absorbed by that substance during such rise in its temperature; and, dividing this product by the thermal units contained in one pound of coal, we obtain the weight of coal necessary to burn, in order to produce the above rise in temperature.

Assume the following:

C = weight of coal burned per hour, in pounds;

W = weight of air passing, expressed in terms of Q, at a temp. t_3;

W_n = weight of the nitrogen in the current, expressed in terms of Q, at a temp. t_3;

W_c = weight of the carbonic-acid gas in the upcast current, in terms of Q, at a temp. t_3;

W_v = weight of the aqueous vapor in the saturated upcast current, in terms of Q, at a temp. t_3;

θ = symbol denoting specific heat;

ϕ = symbol denoting tension of aqueous vapor.

And we may write, from what has preceded,

$$C = \frac{W\theta(t_5 - t_4)}{14{,}000}. \quad . \quad . \quad . \quad \text{(XLII)}$$

Equation (XLII) is a generic equation, and in it W has a general reference to the weight of any substance.

Gaseous Composition of Upcast Current.—In regard to the gaseous composition of the upcast current, it may be thought by many to be so variable as to admit of no practical solution. This, however, is not the case. As previously stated, we must consider such a condition of the current as will make the greatest de-

mand upon the furnace. Such a condition will suppose all the oxygen of the air to be converted into carbonic-acid gas (CO_2), as the result of the slow and active combustions of the pit; this gas being the heaviest gas that could be formed by the natural chemical reactions. This condition is readily determined and the weights of the resulting gases easily figured.

Expression for Weight of Air in Terms of Q.—We assume a certain quantity of air Q, passing along the intake of a mine, at a temperature t_2, and, referring to equation (I) and multiplying by Q, we have

$$W = \frac{1.3253B}{459 + t_2}Q. \quad . \quad . \quad . \quad \text{(XLIII)}$$

Expression for Weight of Nitrogen.—This last equation gives the weight of air per minute passing along the intake. Now we know from the composition of the atmosphere that $\frac{77}{100}$ of this weight is the weight of the nitrogen contained in that air, and which undergoes no change in its passage through the mine; hence we may write for the weight of the nitrogen in the upcast current, remembering that the pressure borne is the barometric pressure less the tension of the vapor at the temperature of saturation ϕ_{t_4},

$$W_n = \frac{1.0205(B - \phi_{t_4})}{459 + t_2}Q. \quad . \quad . \quad . \quad (1)$$

Expression for Weight of Carboni-accid Gas.—The oxygen of the air is the active agent in producing and maintaining combustion, either slow or active; and in its passage through the pit it is converted, in greater

or less proportion, into carbonic-acid gas by its chemical union with carbon, incident to gob-fires, slow combustion of coal, burning of lamps, breathing of men and animals, and, lastly, the combustion of the coals of the furnace. It is readily seen that the formation of carbonic-acid gas is limited by the amount of free oxygen in the current and that when this oxygen is exhausted combustion in any form in the pit ceases; even the furnace fire is smothered and extinguished, which sometimes happens in badly managed pits. Now we know from the composition of the atmosphere that $\frac{23}{100}$ of the weight of air is the weight of the free oxygen in that air; and, again, this free oxygen when converted into carbonic-acid gas forms $\frac{8}{11}$ of the weight of that gas. Hence we may write

$$\tfrac{8}{11} W_c = \tfrac{23}{100} W. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Substituting in this last equation for W, its value taken from equation (XLIII), and reducing, we have

$$W_c = \frac{0.4191(B - \phi_{t_4})}{459 + t_1} Q. \quad . \quad . \quad . \quad . \quad (3)$$

Equation (3), above, presupposes that all the free oxygen of the air is exhausted when the bottom of the upcast is reached. This is the worst condition that can exist, and will make the heaviest demand upon the furnace, relative to gases. If combustible gases are present in the return current, it may be assumed that such gases will burn at the furnace, and that the heat of such burning will be sufficient to raise the temperature of the incombustible gases any probable number of degrees,

independent of the heat of the furnace; such number of degrees may then be deducted from the rise in temperature expected from the furnace. In some instances, in fiery mines, this combustion of gases (properly aerated) at the furnace forms an essential element in heating the air-current; but it should not be relied upon to any large extent, as a general rule, in calculating the size of a furnace.

Expression for Weight of Vapor of Saturation.—We assume the air-current to be saturated with aqueous vapor from contact with the moisture of the pit, which is always the case upon its return, as is evidenced by the sweating of the roof and the sides of the airways, wherever this current is chilled or its temperature falls in the least. The weight of this vapor of saturation is easily determined (its specific gravity as referred to air, at the same temperature and pressure, being 0.6235; see Table V of the Appendix) by the equation

$$W_v = 0.6235 \frac{1.3253\phi_{t_4}}{459 + t_3} Q; \quad . \quad . \quad . \quad (4)$$

or, reducing,

$$W_v = \frac{0.8263\phi_{t_4}}{459 + t_3} Q. \quad . \quad . \quad . \quad . \quad (5)$$

Summary.—Equations (1), (3), and (5), above, give the greatest weight of these three constituents possible in a current; and these are the only constituents of a mine-current which affect the size of the furnace.

Résumé.—We have now determined the weight of each of the gases and vapors passing per minute and composing the upcast current. Each of these gases

and vapors possesses a different specific heat, as previously stated, and this specific heat expresses the thermal units necessary to raise one pound of each gas or vapor, respectively, one degree.

Expression for Weight of Coal to Heat Air-current (Dry Shaft).—Referring now to equation (XLII), which is the general equation for the required weight of coal, and substituting in turn for W its values as taken from equations (1), (3), and (5), respectively, and for θ its value for each respective gas or vapor as given in Table IV of the Appendix, and then adding these three resulting equations together, multiplying by 60 to reduce to hours, and denoting the total coal required by C_1, we have finally, after reducing,

$$C_1 = (0.3394B + 0.0576\phi_{t_4})\frac{60Q}{459+t_8} \times \frac{t_8 - t_4}{14000}. \quad \text{(XLIV)}$$

Equation (XLIV) gives the pounds of bituminous coal burned per hour in raising the temperature of the upcast current from t_4 to t_8 in a dry shaft.

WET SHAFTS.

Prefatory.—When we have a wet shaft to deal with, we assume that the conditions are precisely the same as in a dry shaft, except that we must burn an extra amount of coal in order to evaporate the moisture of the shaft and to raise the temperature of the vapor thus formed from the temperature of evaporation to the temperature of that portion of the shaft where the vapor was formed.

Condition of Shaft.—In a wet shaft, evaporation is

taking place all the way up and down the shaft, below the point where the moisture first makes its appearance. The moisture finds its way through the curbing at or somewhat below the flow, and starts to trickle down the sides of the shaft: this water may or may not all find its way to the bottom of the shaft, according to the strength of the flow; it may all be evaporated before the bottom is reached, as the evaporation is constantly going on.

Temperature of Evaporation.—The evaporation from the sides of the shaft is taking place at all temperatures, from the temperature of the percolating water, which we assume to be 40° F., to the temperature at which boiling takes place, 212° F. Wet boards steaming in the cold air, or wet clothes drying in the wind, are every-day examples of evaporation taking place at low temperatures.

Absorption of Heat.—Evaporation at any temperature is always accompanied by an absorption of heat, which becomes latent in the vapor. This absorption of heat by the vapor cools the upcast current. According to the experiments of Regnault upon the absorption of heat by vapors, and which are more conclusive than the experiments of Watt upon the same subject, this absorption of sensible heat varies as the temperature of evaporation varies. The absorption will therefore be much greater in the lower part of the shaft where the temperature often reaches the boiling-point. The effect of this absorption is to assimilate the temperatures of the upper and lower parts of the shaft, bringing them nearer to the average temperature: the vapor acts as a carrier of the heat from the lower to the upper part of the shaft, absorbing it in the lower and

condensing and giving it up again in the upper cooler portions. This heat of vaporization or latent heat is expressed by the empirical formula of Regnault ; as is also the heat absorbed in raising the temperature of the vapor, after it is formed, to the temperature of that part of the shaft.

Expression for Extra Coal (Wet Shaft).—These formulas of Regnault are empirical, but none the less valuable, as the experiments were carefully made and the experimenter himself reliable.

Assume the following:

w = wt. of water (approx) shaft makes per hour, in pounds;
t_1 = average temp. of upcast shaft;
t_v = average temp. of vaporization;
C_3 = extra coal burned per hr. on account of wet shaft;
1082, 0.305 = constants determined by Regnault's experiment;
0.4805 = sp. heat of aq. vapor (see Table IV, App.).

Then we have Regnault's expressions for

Heat of vaporization . . . . $w(1082 + 0.305t_v)$
Heat absorbed by vapor . . . . . $0.4805(t_1 - t_v)$

These two expressions represent the total heat rendered latent by the formation of the vapor and the raising of the temperature of that vapor to the temperature of the shaft. Adding these together and dividing by the thermal units in a pound of coal, we

find an expression for the extra coal required per hour, on account of the wet condition of the shaft:

$$C_2 = \frac{w(1082 + 0.305t_v) + 0.4805(t_1 - t_v)}{14000}. \quad . \quad \text{(XLV)}$$

The total coal required in wet shafts is the sum of equations (XLIV) and (XLV).

Cooling Effect of Shafts.—Referring again to the "third determination" in the practical problem in the fore part of this chapter, we observe that it is there required to ascertain the temperature of the bottom of the upcast current when we know the average temperature of the shaft; or, in other words, when we know what the *average* temperature of our upcast shaft must be, in order to produce a certain ventilating current, we are hereby enabled to establish therefrom the necessary temperature at the furnace. This determination depends upon a certain empirical coefficient of cooling k_1, based upon the principle that one square foot of the inner surface of the shaft possesses a certain cooling power or conductivity of the heat of the current, by which a definite number of *units of heat* are carried off per minute from the volume of air passing.

Expression for Coefficient of Cooling.—It is obvious that the loss of heat, or fall in the temperature of the upcast current, in different shafts is proportionate to the exposed cooling surfaces of the respective shafts, and inversely proportionate to the weight of air passing; hence assume the following:

o = perimeter of the shaft;
d = depth of the shaft;

Q = quant. of air passing per min., at any temp. (t).
W = weight of air passing per minute.
L = loss of heat or fall in temp. of the current in passing from the bottom to the top of the shaft;
k_1 = relative coefficient of cooling.

And from what has preceded we have the following compound proportion, remembering that the cooling surface of the shaft is indicated by (do), and representing the like quantities in another shaft by the same symbols *primed*:

$$L : L_1 :: \frac{do}{W} : \frac{d_1o_1}{W_1}. \quad . \quad . \quad . \quad . \quad . \quad (1)$$

But, referring to equation (XLIII), we may write the proporticn

$$W : W_1 :: \frac{BQ}{459+t} : \frac{B_1Q_1}{459+t_1}. \quad . \quad . \quad (2)$$

Combining these two proportions, we have

$$L : L_1 :: \frac{do(459+t)}{BQ} : \frac{d_1o_1(459+t_1)}{B_1Q_1}. \quad . \quad . \quad (3)$$

From this last proportion, (3), we may write the equation

$$\frac{Q_1B_1L_1}{d_1o_1(459+t_1)} = \frac{QBL}{do(459+t)}. \quad . \quad . \quad . \quad (4)$$

Now, as we are in search of an empirical formula, the first member of equation (4) (containing all the quantities referring to one shaft) is determined by experiment, and its value denoted by k_1. Experiments should be performed upon several shafts, and the re-

sults averaged, to obtain a reliable value for this coefficient of cooling. Substituting k_1 for the first member of equation (4), above, we have

$$k_1 = \frac{QBL}{do(459 + t)}. \quad . \quad . \quad . \quad . \quad (5)$$

Again, solving with respect to L, and replacing t by t_2, our assumed temperature relative to the quantity Q, we have

$$L = \frac{k_1 do(459 + t_2)}{QB}. \quad . \quad . \quad . \quad . \quad (6)$$

But it is obvious at once that

$$L = 2(t_5 - t_1); \quad . \quad . \quad . \quad . \quad . \quad (7)$$

hence, combining these last two equations, (6) and (7), and solving with respect to t_5; we have, finally,

$$t_5 = t_1 + \frac{k_1 do(459 + t_2)}{2QB}. \quad . \quad . \quad (\text{XLVI})$$

This coefficient (k_1) is relative, having, as we have said, an empirical value which represents in degrees the amount of cooling of one cubic foot of the upcast current due to one square foot of the inner or cooling surface of the shaft. No reliable determination of its value has as yet been made. We assumed previously, in our practical problem in the fore part of the chapter, that this coefficient had a value of 0.5 degree, which is more or less approximate.

CHAPTER VIII.

ECONOMIC DISCUSSION OF THE FAN.

Prefatory.—As remarked in the previous chapter in regard to the furnace, this discussion will treat of the construction of the fan only as such construction affects its efficiency as a ventilating-machine. We will take up in their order the essential or vital points relating to fans and fan construction, a thorough understanding of which is necessary before perfect designing and constructing can be attained.

Efficiency.—We will begin with *efficiency*. Much depends upon the efficiency of a fan. Some fans work better than others, on account of the details of their construction being more perfect: they have been better made; better mechanics have worked upon them. Some *types* of fans work better than others on account of better designing: they have been constructed upon a better principle. The term "Efficiency," as applied to a fan, is a termin dicating the ratio existing or inherent in that fan between the theoretical and the practical work such fan is capable of performing. Thus if we say a certain fan has an efficiency of 90%, we mean that on account of internal friction or defective construction, or some other cause, known or unknown, that particular fan will only perform 90% of its theoretical work; we do not mean that the fan will only supply 90% of the theoretical quantity of air, nor do we mean that it will only yield 90% of the theoretical depression

or water-gauge, but its practical or effective work, denoted by U, will be 90% of its theoretical work, U_1.

Coefficient of Efficiency.—Denoting this coefficient of efficiency by K, as in Chapter VI, we write

$$U = K(U_1), \quad \ldots \ldots \quad (1)$$

or

$$K = \frac{U}{U_1}. \quad \ldots \ldots \quad (2)$$

How Varies.—We see then, from what precedes, that the simple passage of a current of air through a fan requires a certain amount of work, owing to the resistance offered by the fan to the flowing air. This work is practically lost or absorbed in the fan; the balance of the work, which is applied to the movement of the air-current through the mine, is called the *Effective* work. It is obvious, then, that the *efficiency* of a fan depends upon the amount of work thus absorbed by the fan and lost. Let us now investigate a step further, and ascertain upon what the coefficient of efficiency depends, and whether or not it is a constant for the same fan running at all speeds. We observe at once—

First, the work of the fan lost within itself is due wholly to the resistance encountered by the air in its passage through the fan, whether such resistance is owing to defective construction or other cause whatsoever.

Second, that this *resistance* varies as the inner rubbing-surface of the fan and the square of the accelerative * velocity, and material obstructions common to

* The *accelerative* velocity is taken as creative of the internal resistance, for the reason that the accelerative velocity is the measure of

fan-construction; but for any one fan in question the rubbing-surface of the fan and other material obstructions are constant, and the internal resistance of that fan will vary as the square of the accelerative velocity only.

Internal Resistance of a Fan.—We may therefore represent the internal resistance of a fan by the expression $k_2 f^2$, k_2 being a constant factor expressive of the resistance of that particular fan to an air-current having a unit of accelerative velocity.

Work of the Resistance.—The work of this resistance is clearly the work lost in the fan, its expression being $k_3 f^3$, in which k_3 is a new constant. Assume

$u =$ the effective work of the fan for a unit of time;

$u_1 =$ the expended work of the fan for a unit of time;

$u_2 =$ the work lost or absorbed in the fan in a unit of time.

Now, referring to equation (6–XXXVIII) we see that f varies as n^2; hence from what precedes we may write, for the work lost or absorbed in the fan,

$$u_2 = k_4 n^6. \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The coefficients k_2, k_3, k_4 are merely general coefficients.

N.B.—We must note here, that the work *lost* in the fan is dependent alone upon the acceleration f due to the mechanical velocity of the fan, and is in no way affected by changes in temperature or barometric pressure, as is the *effective* work of the fan.

General Expression for the Work of the Fan.—

the force *created* within the motor where the resistance is developed; and it is this *active, energizing* force within the motor that is productive of the *resistance* to the passage of the current through that motor.

Referring now to equation (10–XXXVIII), which expresses the total expended work for one second of time, we see that for any one fan the total *expended* or *theoretical* work of that fan is dependent upon three variables, viz., speed of fan, temperature, and barometer. We may therefore write for that equation the general equation

$$u_1 = c\left(n^4 \frac{B}{459+t}\right), \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

in which c is a constant for any one fan. But as the effective work is always equal to the total expended work, minus the work lost, we have

$$u = u_1 - u_2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Substituting for u_1 and u_2, in equation (5), above, their respective values as taken from equations (3) and (4), above, we have for the general equation for the effective work

$$u = cn^4 \frac{B}{459+t} - k_4 n^6. \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Value of K.—But the value of K, (see equation (2), above) is found by dividing the effective work by the total expended work; hence, dividing equation (6) by equation (4), above, member, by member and reducing, substituting K for its value, we have, finally,

$$K = 1 - c_2 n^2 \frac{459+t}{B}, \quad . \quad . \quad . \quad (\mathrm{XLVII})$$

in which c_2 is a new constant, which we term the *fan constant*, as explained later. Thus we see that the

coefficient of efficiency K is not a constant, but varies with the speed and with the temperature and barometric pressure, but not in the same proportion.

Relative Efficiency at Different Speeds.—Let us investigate further, and ascertain what effect the speed of the fan will have with reference to a maximum and a minimum yield. It is interesting to note in this connection, that if a fan has an efficiency of 95% at a speed of 50 revolutions per minute the efficiency of the same fan, at a speed of 100 revolutions per minute will only be 80%, the temperature and barometric pressure remaining the same. If the efficiency is 90% at a speed of 50 revolutions per minute, the same fan working under the same conditions of temperature and barometric pressure will only present an efficiency of 60% at a speed of 100 revolutions per minute. We note also, from an inspection of equation (XLVII), that for the same speed the efficiency of a fan will vary as the expression $459 + t$ varies, and inversely as the barometric pressure, but not in the same proportion.

Limit of Speed.—We see, from a further inspection of equation (XLVII), that the value of K will become zero when

$$1 - c_2 n^2 \frac{459 + t}{B} = 0,$$

or when

$$n = \sqrt{\frac{B}{c_2(459 + t)}}. \quad . \quad . \quad \text{(XLVIII)}$$

This last equation gives the limit of speed for the fan in question, or the speed at which that particular fan will cease to deliver any air. We must remember,

however, that the quantity c_2 has a particular value for every fan, according as the fan is more or less efficient in its work. This will be explained later.

Maximum Effective Speed.—Let us now determine the *maximum effective* speed, or the speed at which any particular fan will throw its maximum of air at a certain temperature and barometric pressure. Referring to equation (XXXIX), and substituting for K its value as taken from equation (XLVII), we observe that Q will have a maximum value for any particular fan forcing air into any particular mine, when the expression

$$n^4\left(1 - c_2 n^2 \frac{459 + t}{B}\right) \quad . \quad . \quad . \quad . \quad (1)$$

is a maximum; or, as this expression may be written,

$$\left(n^4 - c_2 n^6 \frac{459 + t}{B}\right). \quad . \quad . \quad . \quad . \quad (2)$$

In expression (2), n represents any possible velocity or speed of the fan. Now, denoting the next consecutive velocity or speed by $n + 1$, we have for the corresponding expression, relative to the speed $n + 1$,

$$(n + 1)^4 - c_2(n + 1)^6 \frac{459 + t}{B}. \quad . \quad . \quad (3)$$

Let us analyze these three expressions carefully. From expression (1), we see that the quantity yielded by any fan depends upon two variable factors, relative to the speed of the fan: the first a direct factor, *increasing* as the speed increases; the second an inverse factor, *decreasing* as the speed increases (not, however, in the

same proportion). The first of these two factors represents simply the *speed* of the fan; while the second, as we have seen from equation (XLVII), represents the *efficiency*, which continues to decrease as the speed increases.

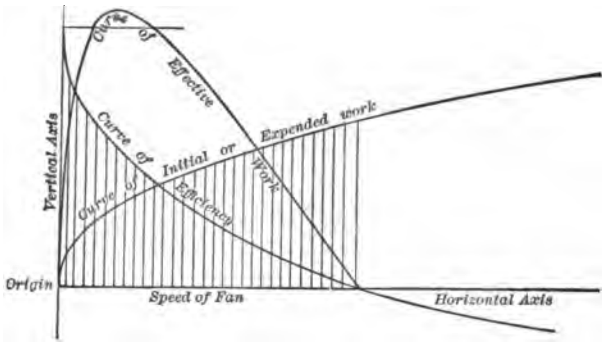


FIG. IV.

Fig. IV represents graphically the relation existing between the power, speed, and efficiency of a fan.

Expressions (2)and (3) are expressions relative to *quantity* for any two consecutive states of speed of the fan. Examining expression (2), we see that its value increases as *n* increases, but not in the same proportion, the rate of increase being less and less as the velocity is higher. For this reason, as we increase the speed by one, the resulting increase of quantity for each consecutive state will be less and less, till finally there ceases to be any increase of quantity for an increase of speed. Previous to this juncture the value of expression (3) has been greater than the value of expression (2), but it now becomes equal to it; and if the speed be increased beyond this point the value of expression (3) will become less than that of expression (2): that is to

say, the quantity of air will diminish from this point until it fails altogether, as shown by equation (XLVIII). Hence it is obvious that to determine that value for n which will give the maximum quantity of air, we must equate expressions (2) and (3), which will give, after reducing,

$$\frac{(n+1)^4 - n^4}{(n+1)^6 - n^6} = c_2 \frac{459 + t}{B} \quad . \quad . \quad . \quad \text{(XLIX)}$$

This is the simplest form of this equation obtainable: it means that the difference between the fourth powers of two consecutive speeds of the fan, at the point of its maximum yield, divided by the difference between the sixth powers of the same speeds, will be equal to the expression given in the second member of the equation. These are important formulas, and reveal the true action of the fan; they should be understood by all who are interested in the question of scientific fan-construction. They show that it is of no avail to speed a fan beyond its maximum effective speed; and it is, moreover, a profligate waste of power, the power being proportionate to the fourth power of the speed (see eq. (10–XXXVIII); and for this expenditure of power we obtain less air than at a lower speed.

To determine Value of K, practically.—This determination should be made in the shop for each type of fan made. The best method is to set the fan up, as will be described later in this chapter under "Testing a Fan"; and having carefully noted the quantity and pressure at a speed of, say, 50 revolutions per minute, increase this speed to 75 revolutions per minute, and note the quantity and pressure again; repeat the same

at a speed of 100 revolutions per minute. Now by referring to equation (XII) we see that the product of these two factors will give the work—in this case the *effective* work (the observations being taken at the point of application); hence, substituting these several products successively for U, in equation (XXXVIII) and solving with respect to K, we obtain the value of K for each of these speeds, respectively. The temperature and barometric pressure must be noted in these observations, and substituted in the equation at the same time. This will give the value of K for certain speeds of the fan and under certain atmospheric conditions.

Value of the Fan Constant.—Referring to equation (XLVII), and substituting therein successively the several values found for K and the corresponding values of n, together with the noted temperature and barometric pressure, and solving with respect to c_2, we obtain the value of this constant, which we call the "Fan Constant," because it has a *constant* value, peculiar to any one fan in question. Knowing the value of this constant, the efficiency of the fan at any speed of the fan may be determined by substitution in equation (XLVII).

Effect of Humidity.—There is one other factor which affects not only the efficiency of a fan, but also its initial work, as expressed by equation (XXXVIII). This factor is the humidity of the atmosphere, or, as we say, its "hygrometric state." Its effect is small, and for all practical purposes may be ignored; nevertheless, as a matter of information, it is well to refer to it. The quantity of air a fan will yield, as expressed by equa-

tion (XXXIX) varies with the cube root of the expression

$$\left(\frac{B}{459+t}\right). \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The coefficient of efficiency K depends for its value upon the reciprocal of the same expression. This expression is taken from equation (I), and relates to the weight of dry air. Now if we write equation (I) so as to express exactly the weight of a cubic foot of air saturated with aqueous vapor, we should have

$$w = \frac{1.3253\,(B - 0.3765\phi)}{459+t}, \quad . \quad . \quad . \quad (L)$$

in which ϕ is the tension of the vapor of saturation at the temperature t (see Table III of the Appendix), the specific gravity of aqueous vapor, referred to air of the same temperature, being 0.6235 (see Table V of the Appendix). Since this effect is so small, we do not burden our equations with its expression; but, for the matter of information, we have prepared Tables VIII and IX of the Appendix, showing the effect atmospheric changes have upon the quantity of air delivered by a fan, the speed being maintained constant (Table VIII), and the effect of the same upon the speed when the power applied remains constant (Table IX). We see from Table VIII that the effect of complete saturation at a temperature of 60° F. amounts to about 0.25% of the yield, while at 90° F. it amounts to about 0.55%. That is to say, if a fan is throwing 100,000 cubic feet of *dry* air at 90° F., it would throw at the same speed and temperature 99,450 cubic feet of air

fully saturated with aqueous vapor, against the same mine-potential.

Résumé.—We have thus far discussed the efficiency of a fan, showing upon what it depends, how it varies, and how it is affected by atmospheric conditions; referring incidentally to the effect of the same upon the initial work of the fan. Let us now take a step further and consider some factors or elements in the construction of the fan, as bearing upon its yield.

Outer Radius or Diameter.—The distinctive dimension of a fan is its diameter. We speak of a fan in terms of its diameter—as, for example, a 10-foot fan or a 20-foot fan; and this is proper, as the radius or diameter more than any other dimension symbolizes the power and determines the comparative importance of the fan as a ventilating motor. As different styles of fans are adapted to different kinds of work, so the various dimensions of a fan have each their respective functions and adaptability to certain portions of the work. We may have a small volume of air to pass through a long or contracted airway; or we may have a large volume of air to circulate through short, expanded airways: in each of these cases the necessary power may be the same, but the kind of work and the style of motor best adapted to perform the work in each case are very different. Referring to equation (XXVIII), we may call it the *elemental equation of power;* because it represents the two elementary factors of ventilation which absorb the power. These two elementary factors of ventilation, *quantity* of air passing, and *mine-potential* against which it is passing, have their representative adjuncts in the several dimensions of the fan. The *diameter* of the fan is the counterpart or repre-

sentative of the *mine-potential;* and the fan whose diameter is thus proportioned to this factor of its work is best adapted to do its work, and will yield the best results. This will be explained fully under General Proportionment of the Fan.

Inner Radius or Size of Eye.—This dimension of the fan is most important, as determining the area of the eye or the size of the inlet of the fan; and as such it is the representative of the *quantity* of air passing. It should, beyond a doubt, be proportioned to this factor. The size of this opening should be such as to accommodate the quantity of air the fan will be required to throw, at a velocity not greater than from 16 to 20 feet per second. In figuring upon this area it must be remembered that the unobstructed area of the two eyes is referred to as the inlet area.

Number of Blades.—The *number* of fan-blades is somewhat dependent upon the size of the fan. There should be as few blades as is consistent with keeping the contained air pressed forward. For all ordinary sizes eight blades make a good number, but when the distance between the blade tips exceeds ten or twelve feet we should begin to increase the number of the blades. In order to reap the best results, the air at the circumference should not be left unsupported. A good plan is to introduce small or secondary blades at the circumference of the fan, running inward only half as far as the other blades; the air is thus supported at the circumference and the friction at the inlet is not materially augmented.

Width of Blade.—This is a most important dimension of the fan, although one which has been ignored by writers. Why this is so is hard to understand.

It is possible that this omission occurs from the failure to distinguish between *static* and *dynamic* pressure, as in static pressure the width of the fan-blade divides out (see Chapter II.). This dimension of the fan is the representative of the quantity, as the diameter is the representative of the mine-potential: it should be proportioned to the *quantity* of air the fan is expected to pass per minute. As we have previously stated in the introductory chapter, a high mine-potential always indicates a large quantity of air moving at a comparatively small expenditure of power; and this condition always obtains when several splits are made in the air-current. The typical fan, under such conditions, should have short, broad blades. In fact, however, it is possible, by the adoption of a judicious system of ventilation, and by splitting the air from time to time as the mine becomes more extended, to maintain the elemental equation of power referred to above (eq. XXVIII) at about a constant value. This should be done, and a fan employed having a less diameter and broader blades. This type of construction will be seen to possess a mechanical advantage also, by giving better opportunity for sway-bracing, and will make a stronger fan. Such a fan, under the conditions stated, will be adapted to its work.

Curvature of Blades.—Another point with reference to the blades of the fan is the *form* of blade that will yield the greatest efficiency, or transmit the greatest percent of the power applied. This is a question which has from time to time given rise to considerable difference of opinion, some maintaining that the blades when curved backward from the direction of the motion was best adapted to propel the air. We believe there is

but one solution to the question: we give our verdict in favor of the straight-paddle blade, except as the inner edge of each blade should be curved forward in the direction of the motion; the idea of the forward curvature of the inner edge of each blade being to convert the radial motion of the incoming air into the enforced rotary motion of the fan-blades, with as little shock as possible. There is always absorption of power in lost motion or shock; and any device by which this is avoided, by deflecting the course of the current into its proper channels without shock, is an assistance: it will show in the increased

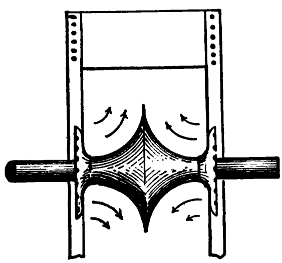


FIG. V.

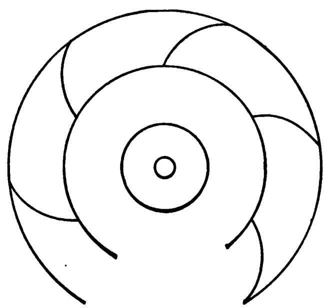


FIG. VI.

efficiency of the fan. A conical arrangement about the shaft, whereby the incoming current would be deflected radially, as shown in Fig. V, would be beneficial in cases where the fan is crowded, or where the intake is at a high velocity; in general, however, this arrangement is unnecessary, as the intake-chamber of the fan should be large, and the velocity at this point thereby reduced to a minimum. Before leaving the discussion of blades, let us look for a moment at the "Murphy" fan, represented in Fig. VI. The characteristic of this

fan is the curved blade: the fan gives fair results, and has many advocates; but we believe that this type of construction will consume a greater amount of power, in proportion to the yield, than the straight-paddle fan. The main point of difference between these two types, with reference to their working, is the *speed:* working under the same conditions and delivering the same amount of air, the speed of the Murphy fan is much the greater of the two. The Murphy fan is in some sense a screw-motor, and as such differs essentially from the straight-paddle fan in its working principle. Certain it is that some of the air is carried around by the revolving blades and expelled by virtue of the centrifugal force thus developed: the amount of air thus contributing to a centrifugal pressure will vary according to the greater or less inclination of the blades; the blades could be so wreathed into a spiral as to convert the fan wholly into a screw-machine, when its action would cease to be anything other than mechanical; and its necessary speed would have to be enormous in order to compete as an air-motor. The reasoning that would lead some to adopt a curved blade is to establish as little friction as possible between the radial passage of the air through the fan and the rotary motion of the blades; but we must remember that whatever tends to decrease the rotary motion of the air in the fan will decrease in the same proportion the efficiency or transmitting power of the fan, because the less the air is revolved the less will be the centrifugal force developed. The equations developed in Chapter VI giving the work, yield, and horse-power of straight paddle fans, do not apply to fans having curved or inclined blades. (See Addenda.)

Expansion of Casing.—The peripheral expansion of the fan casing is another important point in the economic construction of the fan. The reason for such expansion is simple and obvious. Each section of the fan is supplying its quota of air to the conduit or shaft leading to the mine; and the effective power of the fan depends upon the continual and free passage of the air through these several compartments or sections and thence to the mine, the *moving force* behind the current, being the *combined* pressure from all of these compartments. Now if the connection of these compartments with the airways of the mine is cut off during a portion of their revolution by a tight casing, their action ceases for such time, and the power of the fan is diminished. On the other hand, if the peripheral casing be regularly expanded from a point near the cut-off, around the entire circumference of the fan, to the cut-off again, there will be provided thereby a gradual increase of the sectional area of the peripheral space, equal to the augmentation of the flow from each compartment; consequently there will be established a peripheral flow of air about the fan and past the cut-off, having a constant velocity. That is to say, the velocity of this peripheral flow will be the same at any point of the circumference of the fan, and may be determined by dividing the area of the cut-off by the entire flow. The amount of this expansion e (see Fig. VII), multiplied by the width of the fan-blades b, will give the *area of expansion.* This area of expansion should be large enough to accommodate the flow of the air-current at a velocity proportionate to the peripheral velocity of the fan. We say that the velocity of the current in the peripheral space should be proportionate to the

velocity of the blade tips, for the reason that better results will be obtained if the air travels with the fan through this space. If necessary, however, the air will travel ahead of the fan. For like reasons as the above, this expansion of the casing should not be too large, and the air left to travel behind the fan. It is better that the expansion be less and the air urged to travel ahead of the fan rather than behind it, as in the lat-

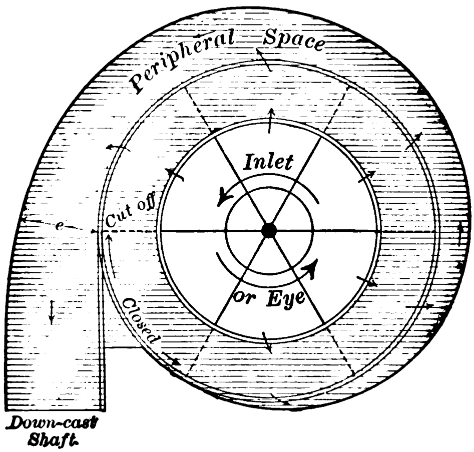


FIG. VII.

ter case there is an opportunity given to baffle. Now, having explained the office of the peripheral space formed by the expansion of the fan casing, let us ascertain carefully the relation and proportion this *expansion* must sustain to the other dimensions of the fan. It will be seen more clearly later that this expansion *e* is the representative and the counterpart of the mine-potential in the elemental equation (XXVIII), and

must be proportioned to this factor of the work. This will be seen readily from a practical problem. For example, from Table X of the Appendix we see that a twelve-foot fan, in order to circulate 25,000 cubic feet of air per minute against a mine-potential of 685.064, must have a speed of 33.7 revolutions per minute; while to circulate the same current against a potential of 342.532, the same fan, working under the same atmospheric conditions, must have a speed of 58.0 revolutions per minute. In each of these cases the same amount of air is passing through the area of expansion at the cut-off. Now, to go back a little, we see that the velocity of the peripheral flow should be maintained as nearly as possible at the velocity of the blade tips, which has changed very materially in the two cases; hence, the same amount of air passing in each case, if we would vary its velocity as the velocity of the blade tips vary, we must vary the area of expansion through which the current flows; but we have already proportioned one factor of this area b to the quantity of air passing, and the other factor e must therefore be proportioned to the potential.

General Proportionment of the Fan.—The three distinctive dimensions of the fan are then, as we have seen, the *Outer Radius*, *Breadth of Blade*, and *Expansion of Casing*. In referring to these elements of the motor we have stated in a general way the elements of the work to which each corresponds and with reference to which it must be proportioned. It must not be supposed, however, that this proportionment of the elements of the motor to the elements of the work is a simple proportioning of element to element. It will be readily seen that these elements so relate to each other

that a change of one necessitates a change of all. For example, a change in the radius of a fan not only results in a change of power, but also in a change of quantity; and the change in quantity necessitates a change in the breadth of blade, which again affects the power. The expansion of the casing is likewise affected by the change of the radius. We propose now, for the benefit of the mechanic interested in the construction of fans, as well as for the mine operator who must decide upon the size of fan that he will need for the ventilation of any proposed workings, to formulate these elements of the motor, expressing the value of each in terms of the work.

Let us have then and retain in our minds a clear idea of *power* as applied to the accomplishment of a certain *work*. The power thus applied finds expression in terms, *factors* or *elements* of the work. We have referred to equation (XXVIII) as the elemental equation of power.

$$U = \frac{Q^3}{X^2}. \quad . \quad . \quad . \qquad \text{(XXVIII)}$$

The second member of this equation designates the elements of the work—a *quantity* of air Q to be circulated against a *mine-potential* X. This is the work to be accomplished, and these are the elements of such work. As we have seen, these elements of the work have their counterparts or representatives in the motor; and as one or the other of these elements is increased or diminished, its representative part in the motor must be varied, that the motor may be adapted to its work. We must note here that while this proportionment of parts will adapt a certain motor to a certain work, there is yet another factor of the *working* of the motor,

viz., its speed, that will enable it to perform a different work, to which it will be alike adapted.

In deciding upon what size and type of fan will be needed for the ventilation of any proposed workings, we must first know the elements of the work; or, in other words, we must decide upon the quantity of air we wish to put in circulation, and against what potential (size and length of airways, giving the resisting power of the proposed workings). This will determine, according to the above elemental equation, the power we must employ in terms of the work. Let us now find an elemental equation showing the relation between the elements of the work and the elements of the motor. Referring to equation (XXXIX) and assuming a value for the inner radius R_1 equal to $\frac{3}{5}R$, which gives an approximate value for R_2 equal to $\frac{4}{5}R$, and the value of the expression $R^3 - R_1^3$ becomes approximately $\frac{4}{5}R^3$: these factors all then reducing to the expression cR^4, in which c is a constant; and substituting X for its value and assuming constant values for B, say 30 inches, and for t, say, 60° F., we may write

$$\frac{Q^3}{X^3} = c(KbR^4n^4). \quad . \quad . \quad . \quad . \quad . \quad . \qquad \text{(LI)}$$

This is the general equation for the yield of a straight paddle-fan under fixed atmospheric conditions, as assumed. By referring now to Table VII of the Appendix, which gives the horse-powers developed by certain fans at certain speeds and under the same atmospheric conditions as those which we have assumed, we may ascertain the value of the coefficient c, which gives

$$\frac{Q^3}{X^3} = 0.000011944(KbR^4n^4). \quad . \quad . \quad . \qquad \text{(LII)}$$

By combining equations (XXVIII), (XXXV), and (LII), and solving with respect to $H.P.$, we have

$$H.P. = 0.0000000000362(KbR^4n^4). \quad \text{(LIII)}$$

Equations (LII) and (LIII) are general equations, giving the work and the horse-power of a fan in terms of itself, and may be used in estimating upon the size of fan needed for the development of any assumed horse-power, or to circulate any desired quantity of air per minute against any assumed mine-potential. Equation (LII) is the desired elemental equation expressing the relation that should exist between the elements of the work and the elements of the motor, including the speed of the same. But we have said that the fan should be so proportioned that the velocity of the peripheral flow shall not much exceed that of the blade tips. This imposes a new condition upon the proportioning of the parts, which is expressed by the equation

$$Q = 2\pi Rn \times be, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which e is the expansion of the casing at the cut-off. (See Fig. VII.) We assume a value for e equal to $\frac{1}{2}R$, as we have shown that R and e are both functions of the same element of the work; and equation (1) above then becomes

$$Q = 3.1416(bR^2n). \quad . \quad . \quad . \quad . \quad \text{(LIV)}$$

Combining equations (LII) and (LIV) so as to eliminate b, and solving with respect to R, we have, after reducing,

$$R = 512.854 \frac{Q}{Xn\sqrt{KXn}}. \quad . \quad . \quad \text{(LV)}$$

From the same equations we have in like manner, for the value of b,

$$b = 0.00000121 \frac{KX^3n^2}{Q}. \quad . \quad . \quad \text{(LVI)}$$

We have also, as previously assumed, for the expansion of the casing,

$$e = 0.5R. \quad . \quad . \quad . \quad . \quad . \quad \text{(LVII)}$$

Now as equations (LV) and (LVI) express the values of R and b in terms of a work performed at a speed n, the values of these elements are indeterminate until we have decided upon what grade of fan to employ; or, in other words, at what speed of the fan the work is to be accomplished. There are different grades of fans capable of performing the same work at different speeds. We may therefore assume such a value for n as will make b equal to $\frac{3}{4}$ of R. This will make b and R sustain such a relation to each other as will be best adapted to the passage of the current through the fan. Under this supposition, combining equations (LV) and (LVI) and solving with respect to n, eliminating R, we have

$$n = 268.67 \sqrt[7]{\frac{Q^4}{K^3X^9}}. \quad . \quad . \quad \text{(LVIII)}$$

In using equation (LVIII) we must first approximate a value for K, which will then give an approximate value for n. From this value of n, however, the true value of K is found and substituted in the equation, which will then give the true value of n. We see from equation (LVIII) that to maintain the best proportion between the outer radius of a fan and the breadth of

the fan blades necessitates a certain speed of the fan for the accomplishment of a certain work. From equations (LV) and (LVI) we see that as we increase this speed for any one work we obtain a smaller radius and a greater breadth of blade; and *vice versa*. It is therefore possible to obtain a narrow fan of large diameter or a broad fan of small diameter which will be alike adapted to the same work. But when the breadth of blade is taken at about three fourths of the outer radius, the air will pass through the fan with less shock and less internal resistance. These last four equations are important in fan construction, and should be in common use in the shop and at the mine. As we have seen, they have been deduced from the more complicated formula (XXXIX) by approximation, and are only intended to be used in estimating upon the size of fan needed for proposed workings, and in the construction of the same. It is not intended to convey the idea that a different-sized fan should be figured for every mine, but to show the necessity for the proper proportioning of parts, and the adaptation of fans of different sizes and proportions to different workings. It is seldom advisable, where the fan is working fairly well and yielding the necessary amount of air, to make changes, although such changes would be for the betterment of the fan and result in a saving of power; but where there is a scarcity of air, changes may often be made and must be made to increase the supply. In constructing a new fan, however, it will be of great pecuniary advantage to have the new fan adapted to its work. Again, if we cannot build a new fan, we can often, by changing the system of ventilation below, by splitting, or otherwise, so adapt the work to the fan in

use that the required results will be attained. We often see a fan that is expected to throw 100,000 cubic feet of air per minute, when its size and proportions would barely permit the passage of 50,000 cubic feet per minute; and yet the operator has a vague, indefinite idea that, by speeding this fan up, it can be made to throw all the air he will need for future development: and perhaps it *will* supply all the air he will *need*, if he knows as much about the rest of the mining business as he does about fans.

Connection with the Downcast.—The connection of the fan with the downcast shaft requires as much care as the construction of the fan itself. We have determined, in the last paragraph, what the area of expansion, or the area at the cut-off, should be: from this point the area of the air-conduit should increase uniformly till the top of the downcast is reached, care being taken to avoid sharp angles. The cut-off itself should be a sharp, well-defined line, made with a sheet of boiler-plate iron bent back upon itself, and forming, for a short distance on either side of the cut-off, a lining to the fan casing and to the air-conduit, as shown in Fig. VII. The expansion of the air-conduit from beyond the cut-off should not be too slow, as a great deal depends upon getting the air quickly away from where it would hamper the free action of the fan; but its expansion must be regular, and changes in direction be made with curved surfaces, as the occurrence of angles or sudden changes in the sectional area of the conduit gives rise to baffles and eddies. The peripheral casing should be continued tangentially to the outer curve. The expansion of the air-conduit should continue till its sectional area is equal to the sectional area

of the downcast shaft. This downcast area should be, properly, twice the sectional area of the main airways below, and the air-course leading from the foot of the downcast should have the same double area, until the point of the first split is reached. It is a good plan to set the fan as far over the mouth of the downcast shaft as the foundation of the fan will permit. Fig. VII shows the general arrangement of the connection with the downcast shaft.

Testing a Fan at the Shops.—The proper test to apply to a fan at the shop is to place it under conditions as nearly similar to those under which it will be compelled to work at the mine, as it is possible to make them; in other words, to cause it to deliver a certain quantity of air while working under a certain pressure, and then making all the observations and noting them down carefully, as described earlier in this chapter; and from these observations determining the value of the efficiency and of the fan constant, as there described. To conduct this test, which when once done will answer for all fans of that type and need not be repeated for each particular fan, the motor is set up and cased in, the discharge being conducted away by a conduit or box long enough to prevent any baffling of the air, and to insure the taking of accurate observations. A partition is inserted in the conduit, at a distance of, say, fifty feet from the fan, provided with a movable shutter by which the discharge or flow of air may be regulated from the outside; the conduit is extended beyond this point (having a uniform sectional area) far enough to give a regular and established velocity to the discharged current, the object being to provide a means of measuring the current of air produced by the fan: the object

of the partition or regulator is to establish a certain pressure or water-gauge under which the fan will work, and which will represent accurately the dynamic pressure of the mine, due to the resistance encountered by the current in its passage through the airways. A

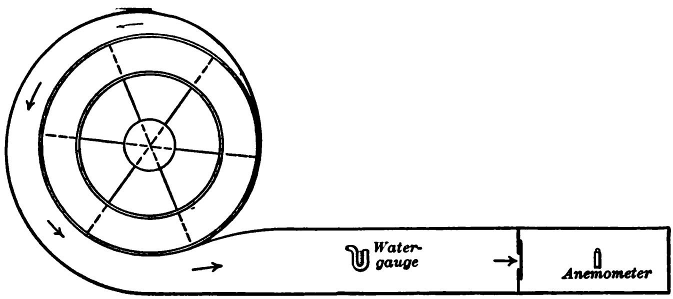


FIG. VIII.

water-gauge is inserted in the side of the conduit, half way between the fan and the regulator, as shown in Fig. VIII, and an anemometer is also placed, as shown, some distance from the open end where the velocity of the current will be uniform. The reading of the anemometer may be taken with an instrument or glass, if convenient, to avoid obstructing the free discharge of the air. The fan is now started and regulated to an exact speed of, say, 50 revolutions per minute; and giving a few moments for the current to establish itself, the shutter is moved in the regulator until a certain fixed water-gauge is obtained, which is noted: as is also the reading of the anemometer, from which the quantity of the current is figured; the temperature and height of barometer being likewise noted and recorded. The experiment is repeated for a speed of, say, 75 revolutions per minute, and like observations recorded; and

again for a speed of 100 revolutions per minute. Now by substituting these recorded results and the known dimensions of the fan in equation (XXXVIII), as previously explained in this chapter, we ascertain the value of K for each speed of the fan experimented upon; and likewise, by substituting in equation (XLVII), as explained, the value of the fan constant for this type of fan may be obtained. The fan contant is the same for any particular type of fan, at all speeds of such fan. The subject of the fan as a motor is one of the most important subjects relating to mine-ventilation, and should be carefully considered in all its bearings, with reference to details of construction, by makers as well as by all others who are in any way connected with the operation of the fan.

CHAPTER IX.

SPLITTING THE AIR-CURRENT.

Advantage of Splitting, as shown by Table VI.—The advantages of splitting the air-current are not duly appreciated. The gain from this source is so enormous as to be, in many cases, disbelieved by practical miners and mine-operators before they have thoroughly investigated the subject. In order to make apparent at a glance the effects of splitting the current one or more times, we have carefully prepared Table VI, showing the respective amounts of work and horse-power necessary to circulate different quantities of air through different mines, and also through the same mine, but using one, two, three, etc., splits successively. The table also shows the unit of ventilating pressure p, water-gauge i in inches, and velocity v in feet per minute at which the current travels.

Mines (assumed).—The table assumes all entries or airways to be $6 \times 8\frac{1}{3}$ feet, giving a sectional area to each individual split of 50 square feet. The lengths of the several air-currents, including the returns, are as follows:

Mine No.	1.	Total	length	of	airway,	1,000	feet.
" "	2.	"	"	"	"	5,000	"
" "	3.	"	"	"	"	10,000	"
" "	4.	"	"	"	"	20,000	"
" "	5.	"	"	"	"	30,000	"

Mine No. 6.	Total length	of	airway,	40,000	feet.
" " 7.	"	"	"	" 50,000	"
" " 8.	"	"	"	" 60,000	"

Quantity Increased.—By inspecting the table, we see that with the same power we can increase the quantity of air any given number of times, by employing a like number of splits. For example, it requires an application of 70.690 horse-power to circulate 25,000 cubic feet of air per minute, in one current, through mine No. 5; but by splitting into two currents we can circulate 50,000 cubic feet per minute in that mine with the same power; and if we split the air into four currents we can circulate 100,000 cubic feet per minute by the application of the same power.

Power Decreased.—Again, we see that it requires the application of 141.379 horse-power to circulate 100,000 cubic feet of air per minute through mine No. 8, employing four splits of the air-current; but if one more split is made, making five in all, the power necessary to drive the same air is only a little more than one half, viz., 72.386 horse-power. These examples serve to illustrate the great importance, from an economic standpoint, which attaches to splitting the air into several distinct currents, to say nothing of the avoidance of danger and delay in case of local accident, when one or more sections of the mine can be immediately and completely isolated.

Limit to Splitting.—A limit to the indefinite splitting of the air-current arises from the consequent reduction of the velocity, which should not be too low, as a sluggish current will not remove the damps or gases which hang in the recesses of the roof and sides,

and in the mouths of old rooms, etc. Again, a high velocity becomes dangerous, especially in fiery mines, where the gases may become ignited by the flame being blown through or against the gauze of the lamp. The limiting velocities of the current may vary some under varying conditions, but practice has shown that the air should not travel less than four nor more than twenty feet per second. At the working face a velocity of five or six feet per second gives good results.

Size of Airways.—There should be a regular size of airway established in the mine, according to the volume of air we expect to circulate, that the velocity of the current may be normal. In the working of low coal it may be necessary to make the airways very wide, where the roof is not taken down, in order to provide a sufficient sectional area. As stated in the foregoing chapter, the air should be brought down the shaft and through an airway having a sectional area double that of the main airways, as far as to the point where the first split is made.

Arrangement of Splits.—As far as possible, all the main splits should be made as near as practicable to the foot of the downcast, and their several returns join the main current likewise near the foot of the upcast. This will reduce the resistance of the pit to a minimum by reducing the distance the current is forced to travel at a high velocity.

Equal Splits.—The word *split*, as used in reference to mine-ventilation, relates to the division of the air-current: as used in this book, a *single split* means a single undivided current; *two splits* signifies that the current is divided, and is travelling in two separate and distinct currents; *equal splits* refers to an equal divi-

sion of the air passing. It is possible without the use of regulators to have an equal division of the air-current between two airways which differ from each other in every respect.

Unequal Splits.—Where the division of the air between two airways is not equal, they are referred to as *unequal splits.* This is the case in the large majority of instances where the ventilating current is divided either by the use of regulators or naturally.

Natural Division.—Now, let us ask, upon what principle or in obedience to what law does the division of air between two or more airways take place? We will state here in answer to this question, what will be explained later in the chapter, that the division of the air-current is, in obedience to the law, that *action and reaction are always equal.* Let us consider for a moment two airways open alike to the free passage of the ventilating current. It is by means of these airways that the current is to find egress from the mine; behind it is the power of the motor urging it forward against the resistance of the airways: it is the resistance that produces and maintains the ventilating pressure; the power behind compels this pressure to move at a certain velocity until, exhausted, it reaches its limit, and the avp of the airways is the work U applied to the current. Now, between the works being performed in these two airways, counterbalanced and held intact by the power of the intake current, there exists a *dynamic equilibrium:* here is the reaction of moving forces; the reaction is square foot against square foot of sectional area. We see now clearly that the *units of work,* or the work transmitted by one square foot of sectional area, must be the same for each split. The expression

for this unit of work, in terms of the airways and their respective currents, is

$$\frac{1}{a}\left(\frac{ksQ^3}{a^3}\right) \text{ or } \frac{kloQ^3}{a^4}, \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which l is the length of the split, o the perimeter of the airway, etc., etc. Hence we may write

$$\frac{loQ^3}{a^4} = \frac{l_1o_1Q_1^3}{a_1^4}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

from which we may write the proportion applicable to all cases of splitting where the division is natural; that is to say, where no regulators are used.

$$Q : Q_1 :: \sqrt[3]{\frac{l_1o_1}{a_1^4}} : \sqrt[3]{\frac{lo}{a^4}}. \quad . \quad . \quad . \quad . \quad (\text{LIX})$$

If the splits in question have the same cross-section, but their lengths vary, we have

$$Q : Q_1 :: \sqrt[3]{l_1} : \sqrt[3]{l}. \quad . \quad . \quad , \quad . \quad . \quad . \quad (\text{LX})$$

If they vary in their length, and their perimeters are different while their sectional areas are the same, we have

$$Q : Q_1 :: \sqrt[3]{l_1o_1} : \sqrt[3]{lo}. \quad . \quad . \quad . \quad . \quad . \quad (\text{LXI})$$

Regulators.—Regulators are devices by which the division of the air is controlled and regulated at will. There are two ways or methods by which proportionate division may be accomplished; and though seemingly similar to the casual observer, they are based

upon essentially different principles and accomplish very different results.

Present Method.—The method in general use at the present time is to place a resistance upon the return of those splits which will naturally take more air than the desired amount; the resistance thus introduced being created by means of an obstruction, as a curtain or door having a movable shutter, placed in the entry so as to retard the flow of the air. The *work* of the *box-regulator* is discussed and shown in the Addenda; but we will say here, that the immediate practical effect is to increase the ventilating pressure of that split, so that the *unit of work* $\left(\frac{Qp}{a}\right)$ will be the same for all the splits in question. We readily see that the unit of ventilating pressure in any split will be inversely proportionate to $\left(\frac{Q}{a}\right)$, or to the velocity v in that split, and that by enlarging or contracting the opening in the regulator any desired proportionment of the current may be secured. From what we have shown thus far, it is readily seen that in this method of splitting by the use of box-regulators the work performed in each split is exactly proportional to the sectional area of that split, regardless of the quantity of air passing in that split; for the reason that the *unit of work* at the point of split is the same for each, and the full area of each is left exposed at its mouth, and each split consequently absorbs an amount of work avp proportionate to its area a. It follows, further, that the work performed in that split in which there is no regulator, as indicated by the expression $\left(\frac{ksQ^3}{a^3}\right)$ is the measure of

the work performed in each split, starting from the same point; and the total work of these splits will be found by multiplying the work in this free split by the number of splits.

Objection.—The objection to this method is a serious one; viz., it requires the introduction of a large amount of foreign resistance into the airways, and the consequent absorption of power, for which the operator receives no return. This absorption of power is large, as will be shown later.

Another Method.—Another method, and one which has the advantage of not introducing any foreign resistance into the airways, is to divide the intake air approaching the mouths of two or more splits so as to apportion the applied power, the avp of the main current, to the works of the several splits, $a_1v_1p_1$ and $a_2v_2p_2$, respectively. This is accomplished by the use of a form of regulator to be described later, by which the exposed area A_1, A_2, etc., of each split, respectively, is made proportional to the above respective works of those splits, according to the proportion

$$A_1 : A_2 :: a_1v_1p_1 : a_2v_2p_2;$$

and by substitution and reduction we have

$$A_1 : A_2 :: \frac{l_1o_1Q_1^3}{a_1^3} \frac{l_2o_2Q_2^3}{a_2^3} \quad . \quad . \quad . \quad . \quad . \quad \text{(LXII)}$$

From this proportion the exposed areas of the various splits may be determined, and the moving forces $pA_1 = p_1a_1$ and $pA_2 = p_2a_2$ proportioned to their respective works. (See Fig. XI.)

Pro and Con.—It has been said by some, though not with much apparent forethought, that if such division of the air were to be made at the mouth of the split it would not have the effect to change the moving force pa; arguing that, as the sectional area of the airway again enlarges to the regular size immediately behind the point of split, the same moving force would be again established: forgetting that there is nothing there to re-establish the unit of ventilating pressure p, and that in the expansion of sectional area immediately behind the point of split, the unit of pressure has fallen from p to p_1, which latter pressure, p_1, is maintained by the resistance inherent in this particular split. We stated in the introductory chapter that the dynamic pressure which animates the current is created and maintained by the resistance ahead of the current, upon which it is directly dependent, and not upon the power behind it. Were it not for this resistance there would be no pressure; we would have an illustration of the third case cited under "Measure of Force," in Chapter II.

Illustration.—This can be proved in a very simple and conclusive way, by taking a short tube connected near one end with a water-gauge, as shown in Fig. IX, by which the pressure in the tube will be indicated any

FIG. IX.

moment. If we blow into the end marked a, the other end being open, there will be no appreciable pressure

indicated by the water-gauge; but if we now lengthen the tube by the successive additions of lengths of tubing to the end marked *b*, blowing as before into the tube at *a*, we will observe a continual rise of pressure for each additional length: such pressure, as in the mine, being created and maintained by the resistance offered by the tubing to the flow of air.

Conclusion.—It is then a most important point to be borne in mind, viz., that the unit of ventilating pressure p is created and maintained directly by the resistance ahead of the current, the power behind the current giving motion or velocity; thus these terms become correlative, but each has its particular source or derivative. It is as the spring between the bumpers of a railroad train being pushed up a grade—the steeper the grade, the greater the resistance and the consequent pressure upon the spring: the power of the engine imparts the motion or velocity to the train; but it is perfectly evident that the resistance regulates the pressure upon the spring: this is analogous to the condition which exists in the mine with reference to the ventilating pressure. Reasoning further, we see that as each split has its own particular resistance, it *should* have its own unit of ventilating pressure, denoted by p_1, p_2, etc., respectively. Each split will have its own particular velocity, denoted by v_1, v_2, etc., respectively, dependent upon the quantity of air required and the sectional area of the split or airway. Hence, as an evident consequence, the work to be accomplished in each split and the power applied at the mouth of each split, and consequently the exposed areas A_1, A_2, etc., at the mouth of each respective split should be proportional to these factors, p_1v_1, p_2v_2, etc., respectively. Let us now summarize

THE THEORY OF SPLITTING AIR-CURRENTS.

Dynamic Equilibrium.—We all understand what is meant when we speak of static equilibrium or the equilibrium of pressures; but we may not so clearly comprehend the meaning of the term *dynamic equilibrium.* When a force is exerted to produce motion against resistance, as alluded to in Chapter II, there is developed a dynamic or moving pressure, which in connection with the velocity becomes the measure of the force; this measure (see Chapter IV) we call *work.* In the illustration previously referred to, where the engine is pushing a railroad train, the dynamic pressure there developed is represented by the compression of the spring between the bumpers. This dynamic pressure, as we have seen, is a factor of the *resistance* under which the moving force is acting, and is always present as an active agent; in no way promoting or retarding the movement of the body, only as it acts as a medium between the *resistance* and such portion of the *moving force* as is neutralized by that resistance, thereby establishing a *dynamic equilibrium* between these two components. This affords us a clear comprehension of the forces at work and concerned in the movement of a fluid mass. As stated above, the measure of the applied or moving force is this dynamic pressure taken in connection with the velocity of the movement; in other words, the product of these two factors pv, which is, as we have said, the *work* of the force.

Theory of Splitting.—Now for the theory of splitting; and by this we mean simply the action of the laws concerned in the splitting or dividing of currents

of air. When a split is established in an air-current, and the air is passing in proper proportions through the respective splits, there is established at the point of split a dynamic equilibrium of the moving forces; in other words, these forces react against each other. Unit of pressure (pressure upon a unit of surface) reacts against unit of pressure; and since action and reaction are always equal, the units of work (the measure of such reaction) will be equal. Hence we may write

$$pv = p_1v_1. \quad . \quad . \quad . \quad . \quad \text{(LXIII)}$$

Caution.—Equation LXIII is always true at the point of reaction; but we must not mistake the units of work at this point for the units of work back in the entry where the sectional area is enlarged to the regular size. The areas at both of these points are transmitting the same work obviously: it could not be otherwise. Now if the work to be performed in the respective splits is different, and the *units of work* at the point of split are equal, our problem is simply to proportion the exposed area at the mouth of each split to the work to be accomplished in that split. The unit of work as here spoken of is the work transmitted by one square foot of sectional area. This is the whole theory of the splitting of air-currents.

At the point of reaction or the point of split the units of work (work transmitted by one square foot of sectional area) are equal; and the exposed areas at the mouths of the several splits must be proportioned to the work to be performed in each respective split.

Graphic Method.—There is still another method of demonstrating this important law; and in order to

make more plain the action of the law, as well as to aid the practical mind to retain the points gone over, we will resort now to an every-day illustration. If a certain blow will drive a certain nail one inch into a block of oak, the same blow will drive the same nail two inches into a block of pine: applying this principle to the movement of air in mines, let us suppose we have a current of 100,000 cubic feet of air per minute coming down the intake A, animated by a certain unit of ventilating pressure p. Arriving at a, there are two entries or splits open to its passage or egress: the one, B, 10,000 feet long; the other, C, 5000 feet long. Each of these splits has its respective resistance or back pressure, analogous to the respective densities of the oak and pine blocks referred to above. Now the force applied, corresponding to the blow upon the nail, is the unit of ventilating pressure multiplied into the sectional area of the entry, or pa, the moving pressure. This force is applied alike to each of the splits B and C, and, following out the analogy, will drive the air further in one minute of time in the short split C than in the longer split B. In other words, the resulting velocity, and consequently the quantity, will be greater in the short split than in the longer one; but the work accomplished in each split will be the same, because the same moving force pa is applied to each split under the same conditions, and must perform the same amount of work in the same time. The hatched portions of each entry (Fig. X) represent the respective quantities or velocities in the two splits. Now in performing their work the moving forces applied to the splits B and C react against each other and against the moving force in the main entry A; this is evident. The reaction is unit of area

against unit of area, square foot against square foot; hence it is evident that the units of work or the work transmitted by a unit of sectional area at the point of split will be the same. It is important to notice that the units of ventilating pressure may be unequal although reacting against each other, the rebound from such re-

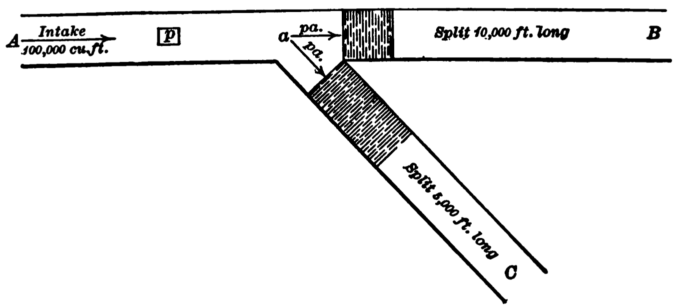


FIG. X.

action being through different spaces, or, in other words, the resulting velocities being different. The unit of ventilating pressure in the direction of either split cannot be greater than the resistance of that split will support; as we have previously seen, it is the resistance ahead of the current in each split that maintains the pressure for that split.

Style of Regulator proposed.—The style of regulator proposed by the author to accomplish the proportionate division of the intake area, and give to the mouth of each split an exposed area proportioned to the work to be accomplished in that split, is shown in Fig. XI. In this figure *bc* is a door hinged at *c* and provided with a set-lock at *b*, by which the door may be fixed and held firmly in any desired position. The current of air com-

ing down the intake *A* strikes the edge of this door *b* and divides. It is evident that any proportionate division of the air may be made, as the door may be set so as

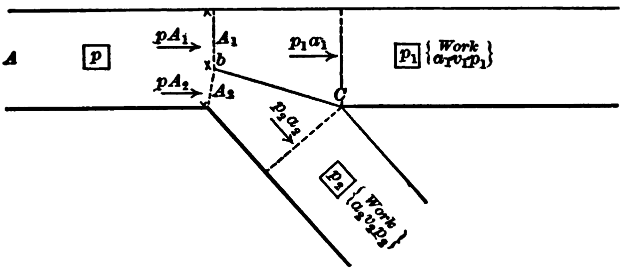


FIG. XI.

to almost entirely shut off the current from passing into the shorter split, by which it seeks to find egress from the mine, and cause it to almost wholly pass through the longer split.

Argument.—The question has frequently been asked by intelligent men, "Wherein does this form of regulator differ from the one already in use, and upon what different principle is its action based?" It may be asserted by some, after a cursory investigation, that there can be no essential difference, claiming that it obstructs the entry in the same manner and to the same degree as does the shutter-regulator. Such claims are based upon no fact. The difference lies in the fact that the splits having a small resisting power are, by the use of this method, ventilated under a low pressure, and not, as in the other method, under a pressure in correspondence with the resistance of the entire pit. This results at once in an enormous saving of power. The mouths of the several splits being left open, in the one method

they are all subjected to the same moving force pa; and, as a result, in those splits where a less quantity of air is desired, or where the resistance is small, a foreign resistance must necessarily be introduced to take up and neutralize this excess of power, or it would apply itself to the movement of more air than is desired in that split. In other words, we introduce into all the lesser splits an amount of dead work to absorb the surplus of power applied to each, making the work to be performed in each of these splits equal to the work of the greatest split in the pit. In the use of the other method the power applied to each split is proportionate to the work of the split.

Illustration.—Let us now assume a practical case. We will suppose mine No. 8 to be passing 100,000 cubic feet of air per minute in four splits, as follows:

Split *a*,	5,000 ft. long	....	20,000 cu. ft.
" *b*,	15,000 " "	....	30,000 " "
" *c*,	20,000 " "	....	30,000 " "
" *d*,	20,000 " "	....	20,000 " "
Total,	60,000 " "	....	100,000 " "

If there were no regulators used in any of these four splits, the air would divide itself as follows:

Split *a*	33,898 cu. ft.
" *b*	23,390 " "
" *c*	21,356 " "
" *d*	21,356 " "

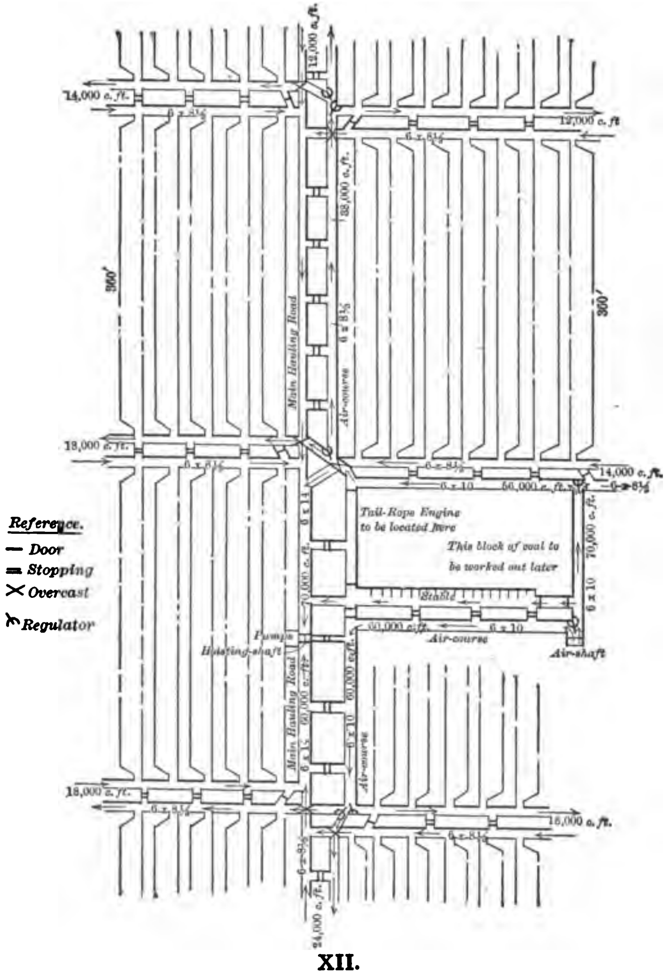
Now it is evident that to obtain the desired quantities of air in the various splits some artificial means must

be resorted to that will decrease the flow into sections *a* and *d*, and cause a corresponding increase in *b* and *c*. As we have seen, the means adopted and in use at the present time is to place an obstruction—a so-called "Regulator"—upon the return of those splits which naturally take more air than the desired amount, thereby driving more air into the other splits which are deficient. We have had this method under discussion in the preceding pages, and we believe it has been proven to result in a profligate waste of power; nevertheless, to make this more plain, we have tabulated below a comparison of the horse-powers consumed in the two methods alluded to, which should not fail to convince any who still remain skeptical.

	Length, ft.	Nat. Div., cu. ft.	Req'd Div., cu. ft.	H. Power, Old Way.	H. Power, New Way.
Split *a*...	5,000	33,898	20,000	81.439	6.030
" *b*...	15,000	23,390	30,000	81.439	61.079
" *c*...	20,000	21,356	30,000	81.439	81.439
" *d*...	20,000	21,356	20,000	81.439	24.121
Total...	60,000	100,000	100,000	325.756	172.669

From this table we see that the same results are obtained in both cases with the expenditure of but little more than 50% of the power in the new method than is required in the old.

Objection.—It has been further objected that the placing of a door or any form of regulator at the points indicated would block the main roads and seriously interfere with the working of the mine. But this is not true if the mine is properly planned and a systematic mode of ventilation adopted, as will readily be seen by referring to Fig. XII.


12,000 c. ft.
14,000 c. ft.
6 x 8½
12,000 c. ft
6 x 8½
38,000 c. ft.
300'
300'
Main Hauling Road
6 x 8½
Air-course
18,000 c. ft.
6 x 8½
6 x 8½
14,000 c. ft.
6 x 10
50,000 c. ft.
6 x 8½
6 x 14
Tail-Rope Engine
to be located here
This block of coal to
be worked out later
70,000 c. ft.
Reference.
— Door
= Stopping
Overcast
Regulator
Stable
6 x 10
60,000 c. ft.
6 x 10
Air-course
Pumps
Hoisting-shaft
Air-shaft
Main Hauling Road
60,000 c. ft.
60,000 c. ft.
6 x 10
Air-course
18,000 c. ft.
6 x 8½
18,000 c. ft.
6 x 8½
6 x 8½
24,000 c. ft.

XII.

System in Ventilation.—System in the ventilation of a mine is everything. One of the first points to be considered is the disposition of the main haulage roads with respect to the ventilating currents. A good general rule, though not without exception, is to make the return air-courses the main haulage roads. This plan has many points in its favor: as, the avoidance of doors upon the haulage roads; the freedom of the air-courses from the dust of travel, thereby insuring a pure current of fresh air to the men; the maintaining of a warmer temperature in the hoisting shaft in the winter by means of the heat of the upcast current, thereby preventing the formation of ice, which otherwise often incapacitates the hoistways; the moving of the loaded cars through the entries in the same direction with, and not opposed to, the circulating current, thereby offering no resistance to the ventilation of the mine. (The resistance to the ventilating current arising from this cause, when the output is moving against the air, is often very considerable and almost as often overlooked by the one in charge, the sluggish circulation being attributed to some other cause.) This paragraph may seem a digression from the subject-matter of the chapter, but it bears directly upon it, inasmuch as it refers to that system of ventilation which will permit of the arrangement of regulators at the mouths of the several splits without interfering with the working of the mine.

Effect of Dips and Rises.—There is one more topic that demands our attention before leaving this branch of the subject. It is the effect upon the circulating current produced by a rise or a dip in the airway. We have seen in Chapter III, in the discussion

of "Dips and Rises," that a dip or a rise in an airway becomes a natural factor of ventilation. Its effect upon the proportionate splitting of the air-current is sometimes misleading, because unlooked for. We often hear the question asked, "Will an entry going to the rise or to the dip receive its proportion of air, if from any cause the total quantity of air furnished to the pit is increased or decreased, no change being made in the regulator?" We answer, undoubtedly the proportion will change for every change in the total quantity of air passing.

Example.—To illustrate: Let us suppose that we have 100,000 cubic feet of air passing into our pit per minute; and we have divided this air so that one split running level is receiving 50,000 cubic feet of this air, and another split running to the rise is likewise receiving the same amount. If now a fall occurs on the main air-course, so that the total supply of air to the mine is thereby reduced from 100,000 cubic feet to 80,000 cubic feet per minute, we will then find that the split running to the rise is receiving less than its former proportion of the entire circulation; i.e., less than 40,000 cubic feet of air per minute. If, on the other hand, the circulation of the pit is increased to, say, 120,000 cubic feet of air per minute, this split running to the rise will receive more than its former proportion of the air; i.e., more than 60,000 cubic feet per minute. In the case of a split running to the dip, the dip-split will take more than its proper proportion when the circulation of the mine is decreased, and less than its proper proportion when the circulation is increased. These results may be tabulated as follows:

	Rises.	Dips.
Circulation increased...........	More.	Less.
" diminished.......	Less.	More.

Cause for Disproportion.—The cause for such disproportionate splitting is simple and obvious. There exists in every dip-split, as explained in Chapter III, an independent factor of ventilation or a ventilating power which is generally positive, rarely ever negative. In the illustration cited above, where 100,000 cubic feet of air are passing per minute, this ventilating power in the dip-split is responsible for, say, 10,000 cubic feet of this circulation within the limits of the split; i.e., this factor of ventilation, existing in this split by virtue of its dip, is potent to draw upon the main current at the point of split for 10,000 cubic feet of air per minute, and to circulate this amount through the split. The balance of the circulation in the split and throughout the pit is dependent upon the ventilating motor. Now, the occurrence of a fall in the main entry outside of the split in question, reducing the flow of air in the main entry at the split to 80,000 cubic feet of air per minute, does not affect the potency of the ventilating power existing in the split; and the split still continues to draw from the main current, independent of the motor, the 10,000 cubic feet per minute, which is the capacity of its own inherent power. This draught upon the main current will continue as long as there is sufficient air passing in the entry to supply the demand; and we further venture the assertion that should the fall so choke the main entry as to reduce the total supply of air to 10,000 cubic feet per minute, all of this air, upon reaching the point of split, would

pass down the dip-split, and none would find its way into the other airway.

Effect Tabulated.—Now, to make plain the foregoing, we may tabulate the effect of this independent factor of ventilation existing in the dip-split upon the proportionate division of the air-current as follows:

Before the fall:

Main airway.............	100,000	cu. ft. per min.
Level or rising split, 50%..	50,000	" " due to motor.
Dip-split, 50%...........	40,000	" " " " motor.
	10,000	" " " " dip.

After the fall:

Main airway.............	80,000	cu. ft. per min.
Level or rising split, 48.6%,	38,889	" " due to motor.
Dip-split, 51.4%..........	31,111	" " " " motor.
	10,000	" " " " dip.

Thus, by a reduction of 20% in the total quantity of air passing, the dip-split in this mine takes somewhat more than 1000 cubic feet per minute beyond its proportion at the expense of the other split. Analogous reasoning will show the effect of increasing the circulation, and apply likewise to rise-splits. The above is figured directly from the principle of equation (LIX).

CHAPTER X.

DISCUSSION OF THE "EQUIVALENT ORIFICE."

Prefatory.—Since the application of the method of the "Equivalent Orifice" to the solution of problems relating to fans is coming somewhat into use, a discussion of its merits or demerits will be of value, and perhaps save us from error. The author of this method, M. Murgue, deserves credit for his mathematical deductions; but after all the whole method is, as its author himself says, simply a "fiction." It is a generalization, wherein the passing of a certain current of air through a mine is compared to the passing of the same current through an aperture in a thin plate.

Illustration.—To simplify this and make it plain to

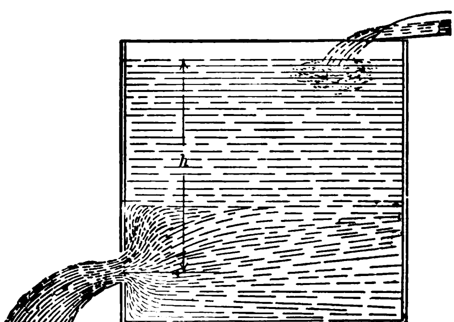


FIG. XIII.

the mind's eye, let us suppose we have a tank of water, as shown in the accompanying figure. One of the sides

of this tank is pierced near the bottom with a round hole. The tank is made of thin boiler-plate. A constant stream of water flowing into the tank above, maintains the level of the water in the tank at a given height h above the orifice. As a result the water issues from the orifice at a constant velocity v, determined by the equation for falling bodies,

$$v = \sqrt{2gh}, \quad \ldots \ldots \quad (1)$$

from which we have

$$h = \frac{v^2}{2g}. \quad \ldots \ldots \quad (2)$$

Now, knowing the area of the orifice a and the velocity of the fluid as it issues v, the quantity of the flow Q will be expressed by the equation

$$Q = av,$$

or

$$Q = a\sqrt{2gh}. \quad \ldots \ldots \quad (3)$$

But the water in the tank is pressing from all directions toward the orifice, giving rise to a baffling and a consequent loss of velocity at the orifice, which is only restored by a contraction of the area the flow just beyond the orifice. This contraction of area, called in Physics the "Vena contracta," is dependent for its amount upon the style of the orifice; but, for a round hole in a thin plate it has been determined as 0.65 of the original area a. Hence we have

$$Q = 0.65a\sqrt{2gh}. \quad \ldots \ldots \quad (4)$$

Now as the laws governing the flow of all fluids under like conditions are the same, and as air is a fluid, it is

suggested by Murgue to assimilate our formulas expressive of the flow of air through mines to the above, letting Q represent the quantity of air passing in cubic feet per second, h the head-of-air column in feet, and a the equivalent orifice of the mine. Reducing this to cubic feet per minute and inches of water-gauge i, we have finally for the value of the equivalent orifice,

$$a = 0.000383 \frac{Q}{\sqrt{i}}. \quad . \quad . \quad . \quad \text{(LXIV)}$$

Equation (LXIV) gives the value of the area of the imaginary equivalent orifice a in terms of the quantity of air passing, and the pressure which animates such current. This is true enough, and so far the analogy drawn is correct, the flow of a fluid through an aperture in a thin plate being correspondent to the flow of air through a mine. Murgue then proceeds to show the practical utility of this imaginary orifice by supposing a fan to be revolving at a uniform speed, discharging its air through two orifices in thin plates successively: one of these orifices he uses to represent the fan and the other to represent the mine. Now, as he says, he has in effect replaced the resistance offered by the fan to the passage of the air through itself, by the first plate, and the resistance of the mine by the second plate. From this point, however, Murgue fails in the application, because he assumes that the effective depression is equal to the initial depression minus the depression caused by the passage of the air through the fan. Let us look carefully at this matter of depressions and first form a clear idea of the significance of the term. It relates primarily to the depression of the water in one

arm of the water-gauge. It is synonymous with "Unit of pressure." Murgue's assumption, then, makes the unit of pressure due to the resistance of the mine plus the unit of pressure due to the passage through the fan, equal to the initial unit of pressure. This is undoubtedly true of the respective works of these pressures, but is not true of the pressure themselves, as was stated in the introductory chapter. No one will deny for an instant that the work lost in the passage of the fan plus the work performed by the current in the mine represents the total work of the fan, or the initial work; but if the sum of the two works is the initial work, the sum of the two pressures cannot give the initial pressure, except and only when the velocities with which these pressures move are equal. In the consideration of falling bodies, the height through which the body falls is generative of the velocity. The method of the Equivalent Orifice treats of pressure in the same manner as generative of, or at least correspondent to, the established velocity. This can only be true for the same equivalent orifice; when the equivalent orifice remains unchanged, the same pressure will always indicate the same velocity. Therefore the fallacy of this ingenious method lies in adding together the pressure due to the passage of the air through the equivalent orifice of the fan (called by its author the "Orifice of passage") and the pressure due to the passage of the same current through the equivalent orifice of the mine, and calling their sum the initial pressure of the fan.

It is important to remember that, while in statics we equate *pressures*, in dynamics *work* must always form the basis of comparison.

Further, we should always study to avoid vague and

imaginative reasonings as far as possible, never dealing in fiction where the case will admit of absolute demonstration. It is due to the failure to reduce his comparisons to a basis of *work* that Mr. Murgue finds no expression in his formulas for the width of the fan-blade, which is a most serious omission; as, also, the temperature of the air and the height of the barometer should appear there. These are all factors which increase or diminish the yield of a fan very materially. What the author has said in this chapter, or elsewhere in the book, must not be understood in the light of criticism, but rather as striving to interpret more truly Nature's laws, and in this we must all be only learners.

CHAPTER XI.

COMPRESSIVE *vs.* EXHAUSTIVE VENTILATION.

Prefatory.—The subject of the ventilation of mines would not be complete without a reference to the relative merits of these two systems. Very little can be said that has not been already said in regard to either of them, and still we find strong advocates of each. As a rule, however, the men who are apparently the strongest advocates of either system cannot give any adequate reason for their preference that will stand the test of criticism. The fact is that both of these systems are valuable, and alike find their particular adaptation to the varied conditions of mine-ventilation. The one or the other should be adopted for any proposed workings only after a thorough consideration and study of the conditions to be encountered in such workings; and not for the reason given by one mining man, much to the amusement of his friends: laying a rope upon the ground, he explained his preference by saying, "You see, gentlemen, I can pull that rope, but I cannot push it."

Plenum System.—Compressive ventilation is representative of what is known as the "Plenum" system. It is ventilation by means of the force-fan or some other motor, by which the air is forced into the mine and through the airways under a pressure greater than that of the atmosphere.

Vacuum System.—Exhaustive ventilation is the

representative of what is known as the "Vacuum" system. It is ventilation by means of the exhaust-fan, furnace, or some other motor by which the pressure in the upcast shaft is reduced and falls below that of the atmosphere.

Difference.—The essential difference between these two systems lies in the fact that the one is a high-pressure system and the other a low-pressure system. The *moving* or ventilating pressure *pa* is the same in both; at least there is no appreciable difference. The water-gauge, showing the difference between the pressures of the intake and the return, will give very approximately the same reading for the same mine under like conditions, when the air is forced by the motor, as when it is exhausted. The same volume of air must be passing in the same direction, under absolutely the same conditions of temperature, barometer, and hygrometric state. It will not answer to observe the water-gauge when the fan is forcing, and then to reverse its action and take the same observation. This would not be an adequate test, although the same quantity of air might be passing at the time of taking the two observations: the obstacles met with and the resistance to be overcome by the current in the mine would not necessarily be the same; and this is a point about which we have to be assured before making the test. In the one system the motor acts to establish a pressure in the mine as much above the atmospheric pressure as it is below it in the other system.

Comparative Effects.—Now, what are the comparative effects of ventilating by these two systems? The system by compression establishes an actual pressure in the pit which is always greater than the atmospheric

pressure, inflating the pit as we would a balloon. As a natural result, the air of the pit seeks vent by every fissure or crevice open to its egress. This may seem a trivial circumstance but in the vicissitudes of mining it has often proved a very important one. The fissures and crevices formed in the roof of the mine by the general sinking of the overlying strata often extend to the surface, frequently opening up seams from which obnoxious and dangerous gases issue. If the air of the pit is under compression these gases will be driven from the pit, in place of being drawn into it, as would be the case were the ventilation exhaustive. This finds even more practical application in the case of the near approach to old workings, in which dangerous gases are very apt to have accumulated. Such accumulations of gases find easy access to a pit under exhaustion; in fact, without warning they may and often are thrown out upon the miner in great volume. The writer remembers at one time tearing out a brattice shutting off some old workings where there had been an extensive fire, and gas had in all probability accumulated in considerable quantity; when the first small opening was made, the sound was like the rushing of a mighty wind, as the air under compression in the pit found vent into the old works, where the air was dead. There was no fear of this possible accumulation of gas coming out, although for the time some of the miners were frightened. Giving the space time to ventilate, the hole was then made larger and the workings entered with impunity.

Again, it is argued in favor of the exhaustive method of ventilation, that accumulations of gases in old rooms, in crevices, etc., do not increase as fast as when they are

driven back by the compression of the air, and are not as great a menance to the safety of the pit. The claim is that these gases are held back in their crevices and corners by the extra pressure of the compressive method; and if at any time this pressure is relieved, by the stoppage of the fan or by a fall in the airway, the pent up gases will then issue in a larger volume and prove more dangerous. In regard to this, we all know that the pressure under which a pit is ventilated, even in the compressive method, falls far short of the pressure necessary to restrain a gas from expanding, or the pressure arising from the tension of such gas. Again, the natural tendency of a body of gas (by the law of diffusion) is to slowly diffuse itself and mingle with the surrounding air, and this tendency is as great under the pressure due to compressive ventilation as it is under the more reduced pressure of the exhaustive method. Were the gas more of a cohesive body, as a fog or other vapor, this argument would be more tenable. It is true that when the fan stops and circulation ceases the airways seem to be at once filled with the issuing gases; but the gases were not pent up by the pressure due to the circulation, nor do they issue now in any greater volume than before the circulation ceased. They are not now, however, brushed away by the passing current, but accumulate where they issue.

An argument uncontrovertibly in favor of the exhaustive method of ventilation arises from the fact that, in the short-sighted economy of the average coal operator, the fan is established at the dump or in close proximity thereto; and it not infrequently happens that the air forced down the shaft to furnish the breath of life to the hundred or so men compelled to breathe it is

partially vitiated before it starts upon its journey, laden as it is with the odors of the gob-pile or the furnace-stack. In this respect the exhaust-fan possesses an unquestionable advantage, as it admits of the downcast shaft being placed entirely away from the other outside works, and thereby insures a supply of the purest air.

Conclusion.—It is better, in order to provide against possible contingencies that may at any time arise, to arrange the fan so that it may be converted immediately from a force-fan into an exhaust, or the reverse of this. This is usually arranged in a very simple manner by constructing an air-tight enclosure in such a way as to cover the eyes of the fan and connect them with the

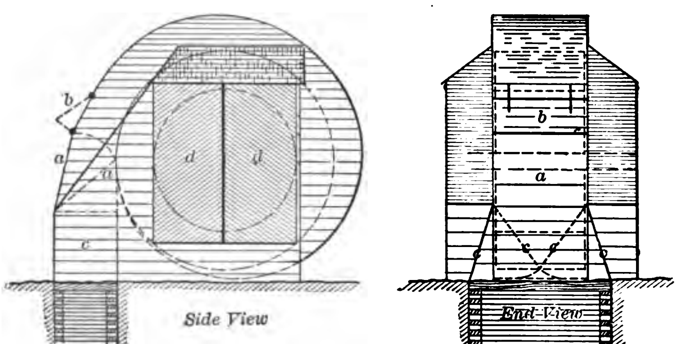


FIG. XIV.

top of the shaft. The enclosure should have a sectional area somewhat greater than the area of the shaft, and must be provided with a pair of doors upon each side of the fan and opposite the eyes, as shown in the side-view and marked *d*, *d*. These doors may have a half-circle cut from each of them, if necessary, so that when shut they enclose the shaft of the fan; when open and the

fan is forcing, they afford unobstructed access of the air to the eyes of the fan. When the fan is forcing, all the doors are closed except the ones *d*, *d*, just mentioned; these are thrown wide open to afford free access for the intake air. The fan is then working in its normal condition. When it is desired to exhaust, the intake doors *d*, *d* are closed, the doors in the side-casing at *c c* are swung back till they meet in the centre of the shaft, thereby cutting off the connection of the mine with the circumference of the fan and at the same time establishing its connection with the eyes; an opening is then made in the face casing of the fan by throwing back the door *a* and raising slightly the door *b*, thus giving free exit to the discharge from the fan. In this position of the doors the fan is an exhaust-fan. All of the doors should be made to fit as tightly in the casing as possible; they may be provided with canvas flaps at the edges, if necessary.

CHAPTER XII.

CARE OF MINE, AS ASSISTING VENTILATION.

Prefatory.— Having gone over the ground, as viewed from a theoretical standpoint, let us now look at a few essential practical points with which every mine manager, every pit foreman, indeed every miner or day-hand employed in the pit should be familiar.

Conduct of the Air.—The distribution and conduct of the air-current through the pit and to the face of the workings should receive the constant and most careful attention of the pit foreman, approved by the mine manager. It is a question of vital importance, both as a source of revenue to the company and health and safety to the men. The carrying of a large quantity of air through an ordinary-sized airway for any considerable distance should only be tolerated when there is no alternative; it is expensive, as the velocity is high and the power correspondingly large; it will also require a constant watching and timbering of the air-course to prevent a fall shutting off the entire section. When possible, the system of ventilation should be such as to distribute the air from the foot of the downcast evenly over the entire pit, without producing a high velocity of the current at any point, and to isolate the different sections of the mine, giving to each its own independent circulation. The velocity of the current in the main airways of the several splits should preferably not exceed 10 or 12 feet per second;

though this velocity may be increased for short distances to 20 feet per second. We find it sometimes higher than this, but always at a large expenditure of power.

Keep Airways Clean.—The airways leading to the workings of a mine should, of all places in the pit, be kept clean and pure. Mules should not be allowed in them at all; and miners, for their own sake, should abstain from any nuisance in them. This should be an imperative rule of every pit, and its enforcement should be insisted upon.

Air Required per Minute per Man.—The fixing of the amount of air which it is necessary to furnish per minute for each man and for each mule is in many respects wholly arbitrary, because the conditions are different in almost every pit, and because the amount of air actually vitiated by the breathing of the men and animals is small in comparison with the amount rendered obnoxious from other causes. Nevertheless, experience has demonstrated and the mining laws of most states and countries now provide for the maintenance of a definite amount of air, which most authorities agree should not fall short of 100 cubic feet per minute for each man and 500 or 600 cubic feet per minute for each mule. But even this law must be modified in mining practice; as, for example, in the working of a thick, fiery seam of coal the above amounts would not be sufficient in the large airways to carry off the accumulating gases; while, on the other hand, in many thin seams, and also in small, non-fiery mines, the above amounts prove much too large. In fiery mines especially, the velocity of the air-current is an essential factor, and hence the required amount of air should be

taken in connection with the size of the airways in all such cases, to insure the necessary velocity.

Room-stoppings.—Another important point is the stopping up of old or abandoned rooms. This should always be done when the gob has a tendency to fire; as is the case when the coal slack has been mixed with the refuse. If the stoppings are built at all they should be well built; for their object is to prevent the air from drawing through such works and maintaining slow combustion in them; this can only be done by making such stoppings practically air-tight. A poor stopping is, in many instances, worse than no stopping at all.

Entry-stoppings.—Entry-stoppings are even more important than room-stoppings; because upon their perfect construction depends the circulation of the entire pit; their leaking permits a constant loss of air into the return, so that the full amount never reaches the face of the workings where it is needed. These stoppings should be built double; i.e., two walls should be built a foot or so apart and the space between them filled with sand or fine dust from the roads. This is work which should not be slighted; it should be left in the hands of men that can be trusted.

Break-throughs. — Small or contracted break-throughs exert an untold influence upon the circulation of a mine. The area of any break-through between entries should not be less than the area of either of the entries. It will often be necessary for a pit boss to see that his orders in this respect are carried out, and compel entry-men to widen all narrow openings. It is a common practice in most mines for entry-men to store their tools in the last break-through, where the air-

current is passing and where every inch of area should be available, instead of carrying them back to the next break-through, which has been stopped, but still affords ample room for the storage of tools. This practice should be prohibited, as it is an imposition upon all the men located upon that air, and an absolute loss to the company, making them furnish more power to obtain the same amount of air.

Double Doors.—When doors are in use upon the main roadway and the roadway at any point taps or opens into the main air-course, such point should always be protected by the use of double doors; i.e., two doors far enough apart that they will not be both open at the same time. This will prevent the temporary stoppage of the circulation of the pit, and is very essential in many instances.

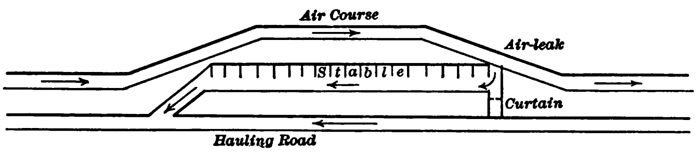
Overcasts.—Every good pit foreman will put in overcasts on the main roadways wherever the development of the cross-entries warrants so doing. They may seem to be expensive, but this initial expense is more than repaid by the saving in current expenses for trappers, to say nothing of the avoidance of delays to drivers, if trappers are not employed. The overcast will always yield a more steady current and avoid the annoyance to the miners of having their air cut off by some careless or indifferent man setting the door open and leaving it so. Did mine managers realize for a moment how much of valuable time is lost to the company from this source, they would permit nothing other than an overcast at these main points. Men cannot and do not work when their supply of air is cut off.

Undercasts.—In some rare instances we find under-

casts preferred to overcasts; but we believe that experience advocates the adoption of the overcast. The author has seen the airway coming from an undercast so filled with fine dust as to be decidedly unpleasant and hurtful to the lungs; the dust arising largely from the roadway passing over the framing, making it practically impossible also to prevent leaking and loss of air.

Angles in Airways.—It will be necessary to draw but a passing attention to the avoidance of all sharp angles in airways generally, but especially in the main air-courses, where such material obstructions add largely to the resistance of the pit.

Stables.—The arrangement of the mine stables is an important point with respect to good ventilation, as too often they are located upon the air-course in such a manner as to taint the air passing into the pit. This is not good judgment, nor is it good policy to place the stables upon the return of the air, without giving to the mules a fresh supply of air. The mule needs pure air and plenty of it for his wholesome, as well as man; treat him well, if you expect him to work well. It is advisable to have the mule stabled as near to his



Inside Stable

FIG. XV.

work as possible; it is also advisable to have his stable located at no great distance from the bottom of a shaft, where he may be rescued in case of accident, and

by means of which his fodder may be sent down and the refuse of the stables hoisted. As far as possible, let these requisites be taken into consideration in the location of the stable; but, in any event, let the egress from the stable be upon the return of the air, and ventilate by means of a small split direct from the air. We would suggest a location similar to that in the accompanying figure. The entry-pillar may be widened at any point where it is advisable to place the stable; or it may be located on the other side of the entry, as shown in Fig. XVI. In this latter arrangement the

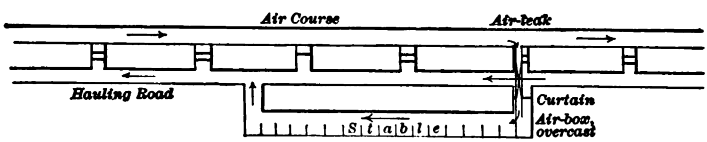


FIG. XVI.

ventilation of the stable should be secured by means of a small split, carried from the air-course by an overcast box. By this means the mules will not be compelled to breathe the outgoing powder-smoke and gas from the workings; they will work better and live longer. On no account should the stable be allowed upon the air-course. The main stable located at the shaft-bottom may be arranged as shown in Fig. XII.

APPENDIX.

TABLES AND PROBLEMS.

TABLE I.

COMPARISON OF THE FAHRENHEIT AND CENTIGRADE SCALES.

Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.
−30	−34.4	70	21.1	180	82.2	280	137.8
−20	−28.8	80	26.6	190	87.8	290	143.3
−10	−23.3	90	32.2	200	93.3	300	148.9
0	−17.7	100	37.7	210	98.9	310	154.4
10	−12.2	110	43.3	212	100.0	320	160.0
20	−6.6	120	48.9	220	104.4	330	165.5
30	−1.1	130	54.4	230	110.0	340	171.1
32	0.0	140	60.0	240	115.5	350	176.7
40	4.4	150	65.5	250	121.1	360	182.2
50	10.0	160	71.1	260	126.7		
60	15.5	170	76.6	270	132.2		

TABLE II.

CONDITION OF THE CURRENT AT THE BOTTOM OF UPCAST.

Constituents.	Symbols.	Weight in Terms of (Q).	Sp. Heat or Thermal Units.	Thermal Units Absorbed.	Pounds of Bit. Coal burned per hour.
		W	θ	$W\theta(t_5 - t_4)$	C
Nitrogen.	N	$\dfrac{1.0205(B - \phi_{t4})}{459 + t_3}Q$	0.2438	$0.2488(B - \phi_{t4})\dfrac{t_5 - t_4}{459 + t_3}Q$	$(0.3394B + 0.0576\phi_{t4})\dfrac{60Q}{459 + t_3}\,\dfrac{t_5 - t_4}{14{,}000}$
Carbonic-acid gas.	CO_2	$\dfrac{0.4191(B - \phi_{t4})}{459 + t_3}Q$	0.2163	$0.0906(B - \phi_{t4})\dfrac{t_5 - t_4}{459 + t_3}Q$	
Aqueous Vapor.	H_2O	$\dfrac{0.8263\phi_{t4}}{459 + t_3}Q$	0.4805	$0.397\phi_{t4}\dfrac{t_5 - t_4}{459 + t_3}$	

TABLE III.

TENSION OF AQUEOUS VAPOR,

AT VARIOUS TEMPERATURES, EXPRESSED IN INCHES OF BAROMETER.

Deg. Fahr.	Tension, inches.	Deg. Fahr.	Tension, inches.	Deg. Fahr.	Tension, inches.	Deg. Fahr.	Tension, inches.
−30	0.010	45	0.316	65	0.616	105	2.18
−20	0.016	46	0.328	66	0.635	110	2.53
−10	0.026	47	0.339	67	0 665	115	2.92
0	0.042	48	0.351	68	0.676	120	3.33
10	0.070	49	0.363	69	0.698	125	3.75
20	0.110	50	0.375	70	0.721	130	4.34
30	0.180	51	0.388	71	0.745	135	5.00
32	0.200	52	0.401	72	0.770	140	5.74
33	0.207	53	0.415	73	0.796	145	6.53
34	0.214	54	0.429	74	0.823	150	7.42
35	0.221	55	0.443	75	0.851	160	9.46
36	0.229	56	0.458	76	0.880	170	12.13
37	0.237	57	0.474	77	0.910	180	15.15
38	0.245	58	0.490	78	0.940	190	19.00
39	0.254	59	0.507	79	0.971	200	23.64
40	0.263	60	0.524	80	1.000	210	28.84
41	0.273	61	0.542	85	1.170	212	30.00
42	0.283	62	0.560	90	1.36		
43	0.294	63	0.578	95	1.58		
44	0.305	64	0.597	100	1.86		

TABLE IV.

SPECIFIC HEATS OF VARIOUS GASES AND VAPORS,

REFERRED TO WATER AS UNITY.

Gas or Vapor.	Specific Heat.
Air	0.2374
Oxygen	0.2175
Nitrogen	0.2438
Hydrogen	3.4090
Carbonic-oxide gas	0.2450
Carbonic-acid gas	0.2163
Ammonia gas	0.5083
Aqueous vapor	0.4805

TABLE V.

SPECIFIC GRAVITIES OF VARIOUS GASES AND VAPORS,

REFERRED TO AIR AS UNITY.

Gas or Vapor.	Specific Gravity.
Air	1.0000
Oxygen	1.1057
Nitrogen	0.9713
Hydrogen	0.0693
Carbonic-oxide gas	0.9670
Carbonic-acid gas	1.5291
Ammonia gas	0.5367
Marsh gas	0.5590
Sulphuretted hydrogen	1.1912
Aqueous vapor	0.6235

TABLE VI.

EFFECT OF SPLITTING THE AIR-CURRENT.

NOTE.—Size of all airways is 6 × 8⅓; making the perimeter 28⅔ feet, and the area of each individual split 50 square feet.

Ref. No.	Quantity, c. ft. p. m.	No. of Splits.	Total Length.	Mine-potential.	Unit of pr.	W.G., inches.	Vel., f. p. m.	Work, ft.-lbs. p. m.	H. Power.	Ref. No.
1	25,000	1	1,000	585.720	3.11	0.60	500	77,758	2.356	1
2			5,000	342.532	15.55	2.99		388,792	11.782	2
3			10,000	271.867	31.10	5.98		777,584	23.563	3
4			20,000	215.781	62.21	11.96		1,555,168	47.127	4
5			30,000	188.502	93.31	17.94		2,332,770	70.690	5
6	50,000	2	5,000	685.064	7.78	1.50	500	388,792	11.782	6
7			10,000	543.734	15.55	2.99		777,584	23.563	7
8			20,000	431.563	31.10	5.98		1,555,168	47.127	8
9			30,000	377.004	46.66	8.97		2,332,770	70.690	9
10			40,000	342.532	62.21	11.96		3,110,336	94.253	10
11	75,000	3	30,000	565.507	31.10	5.98	500	2,332,770	70.690	11
12			40,000	513 798	41.47	7.98		3,110,336	94.253	12
13			50,000	476.967	51.84	9.97		3,887,938	117.817	13
14			60,000	448.843	62.21	11.96		4,665,540	141.379	14
15	100,000	4	30,000	754.009	23.33	4.48	500	2,332,770	70.690	15
16			40,000	685.064	31.10	5.98		3,110,336	94.253	16
17			50,000	635.956	38.88	7.47		3,887,938	117.817	17
18			60,000	598.458	46.66	8.97		4,665,540	141.379	18
19	100,000	5	30,000	942.511	11.94	2.30	400	1,194,379	36.193	19
20			40,000	856.330	15.93	3.07		1,592,505	48.257	20
21			50,000	794.945	19.91	3.83		1,990,632	60.322	21
22			60,000	748.073	23.89	4.59		2,388,758	72.386	22
23	150,000	6	30,000	1131.013	15.55	2.99	500	2,332,770	70.690	23
24			40,000	1027.595	20.73	3.99		3,110,336	94.253	24
25			50,000	953.934	25.92	4.98		3,887,938	117.817	25
26			60,000	897.687	31.10	5.98		4,665,540	141.379	26

TABLE VII.

HORSE-POWER OF DIFFERENT FANS AT VARIOUS SPEEDS.

NOTE.—Dry air; temperature 60° F. Barometer, 30″. Efficiency, 90% at 50 revolutions per minute.

Diam. ft.	Inner Rad.	Width of Blade.	Area of Eyes.	Horse-power. 50 rev.	100 rev.	129.1 rev.
10	2′ 6″	2′ 0″	30 sq. ft.	2.608	27.814	42.919
		2 6		3.259	34.768	53.649
		3 0		3.911	41.721	64.379
		3 6		4.563	48.675	75.109
		4 0		5.215	55.629	85.839
12	3 0	2 6	50 sq. ft.	6.759	72.094	111.247
		3 0		8.111	86.513	133.496
		3 6		9.462	100.932	155.746
		4 0		10.814	115.351	177.995
14	4 0	3 0	50 sq. ft.	14.461	154.247	238.014
		3 6		16.871	179.954	277.683
		4 0		19.281	205.662	317.353
		4 6		21.691	231.370	357.023
16	4 6	3 0	125 sq. ft.	24.821	264.758	408.542
		3 6		28.958	308.885	476.633
		4 0		33.095	353.011	544.724
		4 6		37.232	397.138	612.814
		5 0		41.369	441.263	680.905
18	5 0	3 6	125 sq. ft.	46.594	497.000	766.907
		4 0		53.250	568.000	876.466
		4 6		59.906	639.000	986.250
		5 0		66.562	710.000	1095.584
20	5 6	4 0	175 sq. ft.	81.438	868.674	1340.432
		5 0		101.798	1085.843	1675.541
		6 0		122.157	1303.012	2010.648

TABLE

CHANGE IN TEMPERATURE, BAROM-

SHOWING THE EFFECT UPON THE YIELD OF A FAN RUNNING AT

NOTE.—The conditions are assumed to be such as to yield 80,000

Hygrometric State.	Barometer.	Temperature (Fahr.). −30	−20	−10	0	10	20
			(cubic	feet	per mi	nute.)	
Dry.	29″	80902	80284	79684	79101	78534	77984
	30″	81822	81197	80590	80000	79427	78870
	31″	82721	82089	81476	80879	80300	79737
50% Saturation.	29′	80900	80281	79679	79093	78521	77965
	30″	81820	81194	80585	79993	79415	78852
	31″	82719	82086	81471	80873	80289	79720
100% Saturation.	29″	80899	80279	79675	79086	78509	77946
	30″	81819	81192	80581	79986	79404	78834
	31″	82718	82083	81467	80867	80279	79703

No. VIII.

ETER, AND HYGROMETRIC STATE.

A CONSTANT SPEED AND DISCHARGING INTO THE SAME MINE.

cubic feet of dry air at a temperature of 0° F. and a barometer of 30″.

Temperature (Fahr.)							Barometer.
30	40	50	60	70	80	90	
		(cubic	feet per	minute.)			
77449	76928	76421	75927	75445	74976	74518	29″
78329	77803	77290	76790	76303	75828	75365	30″
79190	78658	78139	77634	77142	76661	76193	31″
77419	76883	76358	75840	75328	74816	74303	29′
78300	77760	77230	76706	76189	75672	75155	30″
79162	78617	78081	77552	77031	76509	75987	31″
77389	76839	76296	75755	75214	74661	74096	29″
78271	77718	77170	76624	76078	75520	74953	30″
79134	78577	78023	77472	76923	76361	75789	31″

TABLE IX.

CHANGE IN TEMPERATURE, BAROMETER, AND HYGROMETRIC STATE.

SHOWING THE EFFECT UPON THE SPEED OF A FAN.

NOTE.—The power applied remaining the same, any change in atmospheric conditions will produce a corresponding change in the speed of the fan, and the quantity of air produced will remain practically unchanged.

The following table is figured from a base of 100 revolutions per minute, at a temperature of 60° F. and a barometer of 30″, the air being dry. The fan is a 12-foot fan, 30″ wide, giving an efficiency of 90% at a speed of 50 revolutions per minute, being the same fan as the 12-foot fan mentioned in Table X; it is also found recorded in Table VII.

Temperature, Fahr.	Barometer, inches.	Hygrometric State.	Revolutions per minute.	Horse-power.
−30°	28	Dry.	95.7	72.094
	30	"	93.4	"
	30	Saturated.	93.4	"
60°	28	Dry.	102.7	"
	30	"	100.0	"
	30	Saturated.	100.3	"
	31	"	99.0	"
100°	28	Dry.	105.8	"
	30	"	102.9	"
	30	Saturated.	103.8	"

TABLE X.

SPEED AND HORSE-POWER OF DIFFERENT FANS AT DIFFERENT MINES.

NOTE.—Mine : Size of all airways, 6 × 8⅛.

Motor : 12-ft. fan, 30 in. wide, 6-ft. eye; area of the two eyes, 50 sq. ft. ; efficiency, 90% at 50 revs. per min. ; max. effect. speed, 129.1 revs. per min. ; limit of power, 111.247 h.p.

Conditions : Temp. 60° F., barom., 30 in., air dry.

Mine No.	Quantity, cu. ft. p. m.	No. of Splits.	Length, Ft.	Mine-Potential.	Revolutions p. m.	Horse-power.
2	25,000	1	5,000	342.532	58.0	11.782
	"	2	"	685.064	33.7	1.473
	50,000	1	"	342.532	112.0	94.253
	"	2	"	685.064	58.0	11.782
3	25,000	1	10,000	271.867	70.3	23.563
	"	2	"	543.734	40.2	2.945
	50,000	1	"	271.867	....	188.507
	"	2	"	543.734	70.3	23.563
4	25,000	1	20,000	215.781	86.5	47.127
	"	2	"	431.563	48.2	5.891
	50,000	1	"	215.781	....	377.014
	"	2	"	431.563	86.5	47.127
	"	3	"	647.344	60.8	13.963

TABLE X. (*Continued.*)

SPEED AND HORSE-POWER OF DIFFERENT FANS AT DIFFERENT MINES.

NOTE.—Mine: Same as before.

Motor: 16-ft. fan, 36 in. wide, 9-ft. eye; area of the two eyes, 125 sq. ft.; efficiency, 90% at 50 revs. per min.; max. effect. speed, 129.1 revs. per min.; limit of power, 408.54 h.p.

Conditions: Same as before.

Mine No.	Quantity, cu. ft. p. m.	No. of Splits.	Length, Ft.	Mine-Potential.	Revolutions p. m.	Horse-power.
5	50,000	2	30,000	377.004	66.4	70.690
	"	3	"	565.507	47.8	20.945
	100,000	2	"	377.004	....	565.521
	"	3	"	565.507	85.6	167.562
	"	4	"	754.009	66.4	70.690
	150,000	4	"	754.009	96.3	238.575
	"	5	"	942.511	77.7	122.152
	"	6	"	1131.013	66.4	70.690
6	75,000	2	40,000	342.532	107.7	318.100
	"	3	"	513.798	72.0	94.253
	"	4	"	685.064	56.7	39.762
	"	5	"	856.330	47.5	20.359
	100,000	2	"	342.532	....	754.021
	"	4	"	685.064	72.0	94.253
	"	6	"	1027.595	51.6	27.927
	150,000	4	"	685.064	107.7	318.100
	"	6	"	1027.595	72.0	94.253
	"	8	"	1370.128	56.7	39.762

TABLE X. (*Concluded.*)

SPEED AND HORSE-POWER OF DIFFERENT FANS AT DIFFERENT MINES.

NOTE.—Mine: Same as before.

Motor: 20-ft. fan, 48 in. wide, 11-ft. eye; area of the two eyes, (net), 125 sq. ft.; efficiency, 90% at 50 revs. per min.; max. effect. speed, 129.1 revs. per min.; limit of power, 1340.432 h.p.

Conditions: Same as before.

Mine No.	Quantity, cu. ft. p. m.	No. of Splits.	Length, Ft.	Mine-Potential.	Revolutions p. m.	Horse-power.
7	100,000	2	50,000	317.978	103.2	942.530
	"	4	"	635.956	55.2	117.817
	"	6	"	953.934	40.1	34.909
	150,000	4	"	635.956	77.6	397.629
	"	6	"	953.934	55.2	117.817
	"	8	"	1271.912	43.9	49.704
	200,000	4	"	635.956	103.2	942.530
	"	6	"	953.934	70.0	279.268
	"	8	"	1271.912	55.2	117.817
8	100,000	2	60,000	299.229	111.8	1131.029
	"	4	"	598.458	58.0	141.379
	"	6	"	897.687	42.0	41.890
	150,000	4	"	598.458	81.9	477.152
	"	6	"	897.687	58.0	141.379
	"	8	"	1196.916	46.1	59.644
	200,000	4	"	598.458	111.8	1131.029
	"	6	"	897.687	73.8	335.120
	"	8	"	1196.916	58.0	141.379

NOTES

EXPLANATORY OF THE TABLES.

TABLES I, III, IV and V need no explanation. Table II is fully explained in Chapter VII.

Table VI.—From an inspection of Table VI we see that by the application of the same power the quantity of air in circulation is increased in the same proportion as we multiply the number of splits. Thus, compare lines 5, 9, 11, 15 and 23; these all represent Mine No. 5, referred to in the early part of Chapter IX; but employing successively one, two, three, etc., splits. (The term "*one split*," as hereused, refers to a single undivided current.) We observe the power in each instance is 70.690 h.p., while the quantities in circulation hold the same proportion to each other as do the number of splits employed.

Again, for the production of the same quantity of air per minute in the same mine, the powers required are inversely proportionate to the cubes of the number of splits employed. Thus, compare lines 15 and 19, or lines 16 and 20, etc., of the same table.

By further inspection of the table we see that the application of the same power to different mines, or to the same mine employing a different number of splits (which is practically a different mine, as far as the circulation is concerned), gives a different water-gauge, according to the quantities of air yielded in each respective case. Thus in the table, line 5 represents a power of 70.690 h.p. applied to Mine No. 5, producing a single current of 25,000 cubic feet of air per minute, moving under a water-gauge of 17.94 inches: in this case, the power is applied to a current compelled to move against a mine-potential of 188.502. Referring now to line 23, we find that by dividing the circulating current into six separate splits, thereby increasing the mine-potential to 1131.013, the same power applied will yield a current of 150,000 cubic feet of air per minute and a

water-gauge of only 2.99 inches. Hence, we see the fallacy of taking the *yield* alone, or the dynamic *pressure* (water-gauge) alone, as expressive of the power of a fan. To say that a fan will yield a certain quantity of air per minute, running at a certain fixed speed, is not significant; nor yet to say that it will produce a certain water-gauge, running at such speed. We must know the power developed by the fan at that speed, which can only be expressed by the union of both these factors. The power of a fan, or the work it is capable of performing, indicates its value as a motor.

Again, we see from the table that the same power applied will produce, under the same atmospheric conditions, quantities proportionate to the respective mine-potentials, or, the mine-potential remaining the same, the quantities will be proportionate to the cube roots of the respective powers.

Table VII.—This table shows the horse-power developed by the fan running at three different speeds, the last being the maximum effective speed; and consequently the powers given in that column will be the limit of power of such fan. In all of the tables relative to fans, we have assumed a temperature of 60° F., a barometer of 30 inches, and a dry state of the atmosphere; we have also assumed all of the fans to show an efficiency of 90% at a speed of 50 revolutions per minute, which efficiency would give a maximum effective speed of 129.1 revolutions per minute. Any one particular fan may have a greater or less efficiency than this; and as a consequence, its maximum effective speed may be above or below this, as the case may be, as also its limit of power.

An important showing of Table VII is the effect of the change of the width of the fan-blade upon the power of the fan—the power varying in the same proportion as the width of blade varies. But, the proportionment of the fan and the adaptability of the different dimensions of the same to work of different kinds have been carefully considered, under the proper heads, in Chapter VIII and will not be repeated here.

Table VIII.—Table VIII is the counterpart of the last preceding table, and shows what would be the effect upon the quantity of air produced, due to change of temperature, barometer, or hygrometric state, were the speed of the fan to be maintained

at a uniform rate. The table presupposes that the power applied is changed in such a manner as to maintain a constant speed of the fan; and is useful for showing the relative yields of a fan under varying atmospheric conditions. For example, if our fan is yielding a current of, say, 80,000 cubic feet of air per minute, at a temperature of 0° F., and a barometric pressure of 30 inches, the air being dry, the same speed of that fan, when the temperature has risen to 90° F. and the barometer stands at 29 inches, the air having become saturated with moisture, will only yield a current of 74,096 cubic feet per minute.

It will be seen from the table also that the effect of saturation upon the yield is very much greater at the higher temperatures than at the lower, amounting at 90° F. to 0.55% of the entire yield, while at 0° F., it is but 0.02%.

The effect of a change of, say, ten degrees in temperature, on the other hand, is less at the higher temperatures than at the lower, being only 0.61% of the yield, in rising from 80° F. to 90° F.; while in rising from 0° F. to 10° F. the effect is 0.72% of the yield. This effect of a rise in temperature, at any point of the scale, is the same whether the air is dry or saturated with moisture.

The effect of a rise or fall of, say, one inch of barometric height upon the yield of a fan is constant, between the same points of the barometric scale, for all temperatures and whether the air is dry or saturated with moisture. This effect is 1.082% of the entire yield when the barometer falls from 31 to 30 inches, and 1.127% when the fall of the barometer is from 30 to 29 inches. The percentage increases slightly as we drop in the scale.

We see from these two last tables that a meteorological change will not produce any appreciable change in the power necessary to circulate a given quantity of air, but will simply vary the speed of the fan. It will take more power to produce a certain speed of the fan in a heavy atmosphere than in a light one. The lesser speed in the heavy atmosphere will produce the same quantity of air per minute and will perform the same work that a greater speed will accomplish in a light atmosphere, so that we conclude that a heavy atmosphere is a benefit to the working of the fan, providing it is not murky or

foggy, so as to largely increase the resistance of passage. On the other hand, the heavy atmosphere may, as we have previously stated, increase to some extent the resistance of the pit, and is a very decided hindrance to the working of the furnace, as the absorption of heat for the same rise of temperature is greatly augmented.

Table IX.—The effect is here shown of a change in temperature, barometric pressure, or hygrometric state upon the speed of a fan operated by the same cylinder pressure or power applied. Our table assumes that the application of a constant power (72.094 h.p.) maintains a uniform speed of fan (100 revolutions per minute) when the temperature of the atmosphere is 60° F., barometric pressure 30 inches, and the air dry; and shows that if the temperature were now to rise to 100° F., the barometer at the same time falling to 28 inches, the air still remaining dry, the speed of the fan, under the same cylinder pressure, would increase to 105.8 revolutions per minute. The saturation of the atmosphere likewise increases the speed of the fan, other conditions remaining unchanged. The power applied remaining the same, the table shows that atmospheric changes produce a corresponding change in the speed of the fan. Atmospheric changes produce a greater effect upon the yield of a furnace than they do upon the yield of a fan, because, in the former case, they affect directly the power of the furnace, which is the power applied to the current; in the latter case they do not affect the power applied, which is the cylinder pressure of the engine, and is assumed to remain unchanged. If this power applied to the current remains unchanged, the quantity passing will also remain unchanged, although there is an almost inappreciable change in the resistance of the mine, which would affect to a small extent the quantity of air passing. This effect is so small, however, as not to be represented in our formulas.

Table X.—This table is for the purpose of showing the comparative work of three different fans, with respect to their adaptability to different grades of work. The atmospheric conditions are assumed to be the same as those used in former tables. Where the fan is incapable of performing the work of any given mine, dashes have been inserted. We do not mean

to intimate for a moment that any one of the fans mentioned is well adapted to *all* of the work of which it is here shown to be capable; for example, the 12 ft. fan is evidently not well adapted to circulate a current of 50,000 cubic feet of air per minute through Mine No. 2, in a single split; although it is capable of doing so, if required. It is crowding its speed a little and the area of its eyes is none too large. The size of fan more suitable for this work would be 42 inches wide and have a 7-foot eye, the outer diameter remaining the same. It is very important that the internal capacity of a fan be proportionate to the quantity of air it is expected to pass, in order that its efficiency may be high. The proportionment of the fan has been thoroughly discussed in Chapter VIII, and a careful study of Table X will serve to illustrate the principles there referred to. Too much attention cannot be given to this part of the subject. A fan not proportioned to its work is like a man staggering under a burden that is too heavy for him; or like a youth compelled to grapple with a problem that is beyond him. The result is dissatisfaction, if not complete failure; and the thumping of the engine, the racking of the frame, and the straining, wearing, and breaking of various parts is evidence of the want of adaptation of the machine to the work it is compelled to perform.

It is worthy of note that the same number of revolutions per minute of any fan, under the same atmospheric conditions, will always develop the same power.

Conclusion.—The study of the tables should prove of great benefit to the practical mind. We do not doubt that many will be skeptical in regard to some of the results; but, as these are in accordance with the known and accepted laws of the mechanics of fluids, they should be received or disproven. Many are the difficulties attending the thorough investigation of this subject; and many are the slight occurrences, sometimes known, but more often unknown to the investigator, which destroy, or at least impair, the results of the most careful observations: a door stands open in the entry; one or more break-throughs are so contracted as not to allow the free passage of the current; loaded coal-cars standing in the entries; dips and rises not taken into account; the temperature of the

upcast not observed; failure to observe and record the temperature and anemometer readings at various points in the pit, so as to obtain the true resistance to the circulating current; leaking of stoppings; escape of exhaust steam from pumps or inspirators into the upcast; influence of steam-pipes extending along the entry; upcast or downcast shafts obstructed by stairways, coverings, tight cages, etc. These and many other affecting causes must render us cautious in our judgment and criticism. Before making investigations, we should always follow the current around the entire pit, carefully noting any conditions which might influence the flow. We may often simplify our task, by setting open one of the main doors and thereby shortening the course of the current. In all investigations of this class, we should carefully avoid being too minute and thus obtaining coefficients which are applicable only to surfaces of exact measurement. Practically, we are dealing with mines in respect to the *general* extent and size of their air-ways; an it is of little moment to us, whether or not we know the precise coefficient of friction for air rubbing against one square foot of the sides of those air-ways. The actual resistance offered by the air-ways of a mine to the circulating current consists mainly of mechanical obstructions, such as entry-timbers, juttings of the ribs, sharp bends or angles in the air-courses, etc., whereby the momentum of the current is broken. What we need and should strive to ascertain is such a coefficient as will express this resistance for the entire mine, reduced to one square foot of rubbing surface and a velocity of one foot per minute. We mention this in closing, because some experiments which have been recently made confine themselves too closely to minute details, which are more valuable as a scientific experiment than applicable to the solution of practical mining problems.

PRACTICAL PROBLEMS.

1. Find the weight of one cubic foot of dry air at a temperature of 30° F. and a barometric pressure of 30 inches?

Ans. 0.0926783 lb.

2. What will be the weight of the same at a temperature of 60° F. and a barometric pressure of 28 inches?

Ans. 0.0715 lb.

3. What will be the weight of one cubic foot of air saturated with aqueous vapor at a temperature of 60° F. and a barometric pressure of 28 inches?

Ans. 0.070996 lb.

Solution.—When air is saturated with any vapor whatever, that vapor supports a pàrt of the barometric pressure equal to the tension of the vapor at the existing temperature; for example, in the case mentioned in problem 3, the vapor of saturation supports 0.524 inch of the 28 inches barometric pressure, and the air supports the remaining 27.476 inches (Table III).

We first find the weight of one cubic foot of dry air at the given temperature (60° F.) and a barometric pressure of 27.476 inches, which gives 0.0701617 lb.

We then find the weight of one cubic foot of dry air at the given temperature and a barometric pressure of 0.524 inch (the pressure borne by the vapor), and multiply this result by 0.6235 (the specific gravity of the vapor, Table V). This last product will be the weight of the vapor saturating one cubic foot of air, which we find to be 0.0008343 lb.

Finally, adding this weight of vapor of saturation to the weight of dry air found above, we obtain for the weight of one

cubic foot of saturated air at the given temperature and pressure 0.070996 lb.

4. What will be the weight of one cubic foot of vitiated air, at the foot of the upcast, assuming that the air is here completely saturated with moisture; temperature 70° F., barometer 30 inches, and the oxygen of the air wholly converted into carbonic acid gas (CO_2)?

Ans. 0.080805 lb.

Solution.—This is the worst case which can occur, as far as the gaseous composition of the current is concerned; for the presence of carbonic oxide gas, or of fiery gases in the current, would aid ventilation; but it is here assumed that the oxygen of the air is wholly converted into carbonic acid gas.

We find the weight of nitrogen and carbonic acid gas which one cubic foot of air would yield, by substituting the given numerical values for their respective quantities in equations 1–XLIV and 3–XLIV; remembering that these gases support only 29.279 inches of the 30 inches barometric pressure, the vapor of saturation supporting the remaining 0.721 inch., being its tension at 70° F. (Table III). The weight of the vapor of saturation is then found, by substitution, in equation 5–XLIV.

As a result, we obtain the following:

Nitrogen	0.0564824 lb.
Carbonic acid gas..	0.0231964 "
Aq. vapor	0.0011262 "
	0.0808050 lb.

5. Referring again to problem 4, and assuming that the average temperature of the upcast is 70° F., while that of the downcast is 60° F., and the depths of both the upcast and the downcast shafts are each 200 feet, what amount of back pressure per square foot of sectional area will be entailed upon the fan, due to such vitiated condition of the upcast?

Ans. 0.83958 lb.

Solution.—We find the weight of dry air at a temperature of 60° F. and a barometric pressure of 30 inches to be 0.0766071

lb. Deducting this from the weight found in problem 4, we have for the difference of pressure due to one foot of vertical height. 0.0041979. Multiplying this by 200, the depth of shaft, we obtain 0.83958 lb. as the back pressure per square foot, or the unit of back pressure.

NOTE.—This is an item which is frequently overlooked in investigations, and it may at times exert a powerful influence over the circulation.

6. Express the unit of pressure found in the last problem, in terms of head-of-air column. (See equation II.)

Ans. 10.96 ft.

7. Express the same in inches of water-gauge. (See equation XXXVI.)

Ans. 0.16 in.

8. What will be the reading of a water-gauge inserted between the intake and the return of an air-split 10,000 feet long; size of air-way (6x8⅓) feet; when 50,000 cubic feet of air are passing per minute, in this split?

Ans. 2.99 ins.

9. Find the horse-power of the air-split mentioned in the last problem.

Ans. 23.563 h.p.

10. What quantity of air is passing per minute through an air-course whose size is (6x10) feet, when the velocity of the current is 10 feet per second?

Ans. 36,000 cu. ft.

11. In a certain mine, 100,000 cubic feet of air is passing per minute, in four splits or currents, as follows:

"A"	split, (6x8⅓)	1000 ft.	long,	15,000	cu. ft.
"B"	" "	8000 "	"	20,000	" "
"C"	" "	6000 "	"	35,000	" "
"D"	" "	4000 "	"	30,000	" "

slide rule comput[ed]

The division is accomplished by the use of box-regulators. What is the horse-power of this pit?

$= \frac{36.6 \times 100000}{33000} =$ 111 H.P.

Ans. 155.177 h.p. (?)

NOTE.—The box-regulators, which are necessary in splits "A," "B," and "D," make the work performed in those splits equal to the work in split "C." This is the great disadvantage of the use of this form of regulator. In the use of the other form of regulator, each split has its own separate work, peculiar to itself, as given in the following problem.

12. What would be the horse-power of the pit mentioned in the last problem, if the division of the air were accomplished by the use of the improved regulator?

Ans. "A" split	0.509	h.p.
"B" "	9.651	"
"C" "	38.794	"
"D" "	16.287	"
Total ..	65.241	"

13. What quantity of air per minute will 100 horse-power produce, under a three-inch water-gauge?

Ans. 21,154 cu. ft.

14. What will be the unit of ventilating pressure, developed by a furnace capable of maintaining an average temperature of 300° F., in an upcast shaft 500 feet deep; the depth of the downcast being the same and its average temperature 60° F.; barometer 30 inches; ignoring the vitiated condition of the upcast air?

Ans. 12.11 lbs.

15. If we have 10,000 cubic feet of air passing down the intake of a mine per minute, having a temperature of 60° F.; and, if we introduce a water-gauge communicating between the first of the air and the last of the return, which gives a reading of 1.5 inches; what will be the volume of air passing per minute upon the return at the point of observation, the temperature here having increased to 70° F. and the barometric pressure at the same point being 30 inches; supposing no augmentation of the volume of the current by gases from the mine?

Ans. 10,230 cu. ft.

Solution.—The weight of air passing per minute through the mine is obviously the same at all points of the air-course, supposing there to be no leaks through doors or stoppings; it is unquestionably the same at the two points of observation. Hence, by referring to equation XLIII, we see that the volumes passing these two points are inversely proportional to the pressures and proportional to the expression $(459 + t)$; and we may write the proportion,

$$Q : Q_1 :: \frac{B_1}{459 + t_1} : \frac{B}{459 + t} \quad \ldots 1.$$

But B_1, the barometric pressure at the point of observation upon the first of the air, may be determined by reducing the inches of water gauge to inches of barometer and adding this to the barometric pressure given upon the return, according to the equation.

$$B_1 = \frac{i}{13.596} + B \ldots 2.$$

Substituting given numerical values for their respective quantities in equation 2 above, and reducing, we find,

$$B_1 = 30.1103 \text{ inches.}$$

Finally, substituting numerical values for their respective quantities in equation 1 above and reducing, we obtain for Q the answer given above, 10,230 cubic feet.

16. Suppose a mine having two shafts, each 200 feet deep, to be ventilated by a furnace. Assume the outside temperature to be 60° F., barometer 30 inches, average temperature of the upcast 200° F.; and also assume the worst condition of the vitiated air possible, as in problem 4, the oxygen of the air having been wholly converted into carbonic acid gas; and the return air being saturated at a temperature of 70° F.; what unit of ventilating pressure will result?

Ans. 2.348 lbs.

17. What unit of ventilating pressure would result in the

above case if the return current was comparatively free from carbonic acid gas, the other conditions remaining the same?

Ans. 3.364 lbs.

18. What unit of ventilating pressure would result in problem 17, were we to ignore the fact that the return air is saturated with moisture just before entering the influence of the furnace; i.e., were we to figure this problem by the method in general use in our text-books?

Ans. 3.255 lbs.

NOTE.—Air saturated with moisture is always lighter, bulk for bulk, than dry air under the same conditions.

19. In a certain mine ventilated by a furnace, 10,000 cubic feet of air are passing per minute, the upcast shaft being 100 feet deep; to what extent would this circulation be increased by building a chimney over the shaft 16 feet high, other conditions remaining the same?

Ans. 10,770 cu. ft.

20. What quantity of air would pass per minute, under the unit of ventilating pressure (3.364 pounds) found in problem 17, supposing the total length of airway to be 10,000 feet, the sectional area of the same 50 square feet, and the perimeter $28\frac{2}{8}$ feet, the air travelling in one undivided current, using Atkinson's coefficient and ignoring the resistance of the shaft?

Ans. 8,222 cu. ft.

21. What quantity of air would pass per minute in the last problem were we to split the current once, the other conditions remaining the same?

Ans. 23,255 cu. ft.

22. What will be the mine-potential in the two cases respectively?

Ans. 1st case, 271.868; 2d case, 543.736.

23. What horse-power is expended in these two cases respectively?

Ans. 1st case, 0.838 h.p.; 2d case, 2.371 h.p.

NOTE.—In problems 14 and 16 we assume that the power applied is changed so as to maintain the same unit of pressure in the airways after the current is split; we have in these two cases a different power and a different quantity of air passing per minute.

24. If we have 100,000 cubic feet of air passing per minute by the expenditure of 70.69 horse-power, the air travelling in a single current, what quantity of air per minute would the same power yield were this current to be divided into two equal splits?

Ans. 200,000 cu. ft.

25. In the last problem, what power would be required to circulate the 100,000 cubic feet of air per minute in two equal currents?

$\frac{\sqrt{u}}{\sqrt{70.69}} = \frac{1}{2}$ or $u = \frac{1}{8} \times 70.69$ = → *Ans.* 8.836 h.p.

26. What water-gauge will be developed in the case just cited, where 100,000 cubic feet of air are passing per minute, at an expenditure of 70.69 horse-power.

Ans. 4.48 ins.

27. What is the unit of ventilating pressure indicated by this water-gauge? *Ans.* 23.33 lbs.

23,30

28. The entire length of airways being 30,000 feet, and the sectional dimensions 6 × 8⅓ feet, what is the mine-potential for a single, undivided current?

Ans. 188.502.

29. What will be the potential for the above mine when the current is divided and travelling in two splits? *Ans.* 377.004.

30. What power would be required to circulate 100 000 cubic feet of air per minute against this potential?

(Ed. Stenger) $\frac{100000}{377004} = \sqrt[3]{u}$ *Ans.* 565.520 h.p.

by

NOTE.—This is too great a power to be transmitted, practically, through a sectional area of 100 square feet (2 splits); we should use in this case from 4 to 5 splits.

31. Employing 4 equal splits, in problem 30, what would be

the required power; and what velocity of the current and water-gauge would result?

Ans. 70.69 h.p.; 500 ft. per min.; 4.48 ins.

32. Reduce 600 feet of air-column to inches of water-gauge.

Ans. 8.83 ins.

NOTE.—One cubic foot of air will weigh $\frac{1}{815}$ of the weight of one cubic foot of water at temperature of 60° F. and a pressure of one atmosphere (14.7 pounds), its specific gravity being 0.00123, referred to water as unity.

NOTE.—One or two problems will be here introduced, for the purpose of showing the actual effect of the vitiated condition of the upcast column; or, in other words, the back-pressure resulting therefrom. These problems are useful in cases of careful investigation, and should then always be taken into account. For practical purposes, however, the condition of the upcast and downcast columns may be considered as identical. (See Addenda.)

33. Suppose a mine to be ventilated by means of a force-fan, the upcast and downcast shafts being each 200 feet deep, size of airways $6 \times 8\frac{1}{3}$ and 30,000 feet long; what horse-power will be required to pass 100,000 cubic feet of air per minute through the mine in four splits; not assuming any differential temperature of the upcast and downcast columns, or the vitiated condition of the upcast, but figuring in the usual approximate manner for practical purposes?

Ans. 70.69 h.p.

34. Assume the same conditions as given in problem 33, and now suppose the average temperature of the downcast (t_2) to be 60° F., that of the upcast (t_1) 70° F., barometric pressure (B) 30 inches, and a vitiated condition of the upcast current; and determine the weights of one cubic foot of the upcast and downcast columns respectively.

Ans. Upcast (W_1) 0.080805 lb.; downcast (W_2) 0.077267 lb.

35. What unit of back-pressure will result from problem 34, the upcast and downcast shafts being each 200 feet deep; and what horse-power will now be required to pass the same quantity of air per minute (100,000 cubic feet)?

Ans. Unit of back-pressure, 0.7076 lb.; actual horse-power, 72.841 h.p.

36. Under the conditions of problem 34, what quantity of air per minute would pass were the horse-power applied 70.69, as figured in problem 33?

Ans. 97,048 cu. ft. per min.

NOTE.—The actual unit of ventilating pressure, as indicated by the water-gauge, should correspond under all conditions of temperature and barometric pressure to the theoretical unit of pressure, as derived from equation XXIII; but in order to this, and for careful determination for purposes of investigation, the varying functions of temperature and barometric pressure must be taken into consideration, as in the above problems.

FAN FUNCTIONS.

37. What is the efficiency of a twenty-foot fan at 50 revolutions per minute (width of blade 48 inches, inner radius 66 inches), which is yielding a current of 172,270 cubic feet per minute, under a three-inch water-gauge; temperature at the time of observation being 60° F., barometer 30 inches, and the air dry?

Ans. 90%.

38. If we now speed the same fan up to 100 revolutions per minute, under the same atmospheric conditions, what efficiency should it show?

Ans. 60%.

Solution.—Referring to equation XLVII., and assuming the temperature and barometric pressure constant, we see that

$$n^2 \text{ varies as } (1 - K),$$

which gives the above result.

39. Assuming that the fan is working against the same potential in problem 38 as in problem 37, what will be the resulting quantity and unit of pressure; and what horse-power will be developed?

Ans. 379,220 cu. ft. per m.; 75.6 lbs. per sq. ft.; 868.674 h.p.

NOTE.—The mine-potential in problem 39 is not large enough for the increased power of the fan at 100 revolutions per minute; as is shown by the resulting unit of pressure and the velocity of the current, which would be almost 32 feet per second. The potential should be increased, in this case, by splitting the air-current, until a normal water-gauge and a moderate velocity is obtained.

40. What is the value of the fan-constant (c_2) in problems 37 and 38? (See equation XLVII.)

Ans. 0.000002312.

41. What is the value of the fan-constant when the yield and water-gauge indicate an efficiency of 85 per cent at 50 revolutions, or 40 per cent at 100 revolutions per minute, temperature being 60° F. and the barometer 30 inches?

Ans. 0.000003468.

42. Give the value of the fan-constant under the same conditions, when the efficiency is 95 per cent at 50 revolutions, or 80 per cent at 100 revolutions per minute?

Ans. 0.000001156.

43. Find the maximum effective speed, under the conditions of problem 42; i.e., when the fan-constant is 0.000001156, the temperature being 60° F. and the barometer 30 inches; or, in other words, at what speed will the fan yield the greatest quantity of air per minute?

Ans. 182.6 rev's per m.

44. Find the limit of speed of the same fan, under the same conditions; i.e., at what speed will this particular fan cease to throw any air under the atmospheric conditions mentioned?

Ans. 223.6 rev's per m.

45. Find the maximum effective speed and the limit of speed for the fan mentioned in problem 40, under the same atmospheric conditions?

Ans. Max. effect. speed, 129.1 rev's per m.; limit of speed, 158.1 rev's per m.

NOTE.—A fan will rarely ever give as low an efficiency as that mentioned in problem 41. The efficiency will frequently exceed that given in problem 42. The Murphy type of fans may present a higher efficiency than that afforded by the straight-paddle fan; but their yield is not represented by equations XXXVIII-XL. The backward curvature of the blades, resulting in a loss of rotary motion to the air, weakens the pressure incident to speed. This type of fan therefore requires a higher speed for the same yield. (See Addenda.)

46. We are opening a mine to be ventilated by a force-fan, straight-paddle; and we wish to provide for the circulation of

100,000 cubic feet of air per minute, in four equal, separate splits; size of airways (6×8) and 50,000 feet long. What size of fan should we adopt?

Ans. Diam. of fan, 18.9 ft.; width of blade, 7.1 ft.; exp. of casing. 4.7 ft.

47. In the last problem, what will be the speed of the fan at which it will throw the 100,000 cubic feet of air per minute, under the conditions mentioned, temp. 60° F., barom., 30"?

Ans. 50.3 rev's per m.

48. Assuming that the value of the fan-constant of this fan is 0.000002312, what quantity of air per minute will it circulate in the mine mentioned, in four equal splits, when running at a speed of 100 revolutions per minute, the temperature being 60° F. and the barometer 30 inches?

Ans. 215,745 cu. ft.

49. What would be the velocity of the intake of the fan in the last problem?

Ans. About 19 ft. per sec.

50. What is the velocity of the blade-tips and the peripheral flow, respectively, in each of the cases mentioned in problems 46 and 48?

Ans. First case: Blade-tips 49.8 ft. per sec., per flow 50.0 ft. per sec.; second case: Blade-tips 99 ft. per sec., periph. flow 108 ft. per sec.

51. What will be the horse-power of this same fan running at a speed of 60 revolutions per minute, assuming the fan-constant to be 0.000002312, temperature 0° F., and the barometer 30 inches; and what will be its efficiency?

Ans. 252.231 h.p.; efficiency, 87.27%.

52. What will be the horse-power of the same fan, running at the same speed, when the temperature is 90° F. and the barometer 28 inches, and what the efficiency?

Ans. 188.727 h.p.; efficiency, 83.68%.

53. At what speed will it be necessary to run the fan under the conditions prevailing in problem 52, in order to maintain the power developed in problem 51?

Ans. 65.1 revs. per min.

54. What is the horse-power of a 12-foot Murphy fan, blades 3 × 3 ft., inclination of blade to the radial at the centre of gravity 30 degrees, fan-constant 0.000001156, at a speed of 100 revolutions per minute, when the atmospheric temperature is 60° F. and the barometric pressure 29 inches?

Ans. 102.314 h.p.

55. What would be the horse-power of a straight-paddle fan of the same dimensions and having the same fan-constant, at the same speed and under the same atmospheric conditions?

Ans. 111.538 h.p.

56. What is the horse-power of a 16-foot straight-paddle fan, blades 5 feet wide and 42 inches deep, running at a speed of 50 revolutions per minute, and showing an efficiency of 90% at this speed; temperature being 60° F. and the barometric pressure 30 inches?

Ans. 41.369 h.p.

57. What will be the horse-power of the same fan under the same atmospheric conditions, at a speed of 100 revolutions per minute; and what will be its efficiency at this speed?

Ans. 441.263 h.p.; efficiency 60%.

58. If a 12-foot fan, blades 3 × 3 feet, running at a uniform speed of 50 revolutions per minute under a 2-inch water-gauge, yields 24,048 cubic feet of air per minute at a temperature of 60° F. and a barometric pressure of 29 inches, what is its efficiency and what is the fan-constant?

Ans. Efficiency, 87%; fan-constant, 0.0000029.

59. Suppose we wish to arrange for the circulation of a current of 100,000 cubic feet of air per minute, travelling in four separate splits, through an airway (6 × 8½ feet) 60,000 feet long;

what size of straight-paddle fan should we adopt, and at what general speed should the fan be run to accomplish this work?

Ans. Diam. of fan, 18.35 ft.; width of blade, 6.88 ft.; exp. of casing, 4.6 ft.; diam. of eye, 10 ft.; net intake area, two eyes, 110 sq. ft.; speed of fan, 54.9 revs. per min.

SPLITTING THE AIR.

60. Suppose two airways having the same sectional dimensions, and whose lengths are respectively 1600 and 5400 feet long, to be open to the free passage of the circulating current; how will an intake current of 10,000 cubic feet of air per minute divide itself between these two entries?

Ans. 6,000 cu. ft.; 4,000 cu. ft.

6480 13520 slide rule comput.

✓ **61.** What is the horse-power of a current of 100,000 cubic feet per minute, circulating in four equal splits; size of airways (6 × 8⅓) feet; total length 25,000 feet?

Ans. 58.908 h.p.

62. Find the total horse-power of the following splits when box-regulators are used:

Split A.	6 × 8⅓ ft.,	5,000 ft. long,	10,000 cu. ft.
" B.	" "	6,000 " "	15,000 " "
" C.	" "	8,000 " "	20,000 " "
" D.	" "	10,000 " "	18,000 " "

Ans. 38.6 h.p.

63. Find the total horse-power of the same splits, using the other form of regulator.

Ans. 22.253 h.p.

64. What will be the sizes of the openings in the box-regulators in problem 62? (See Addenda.)

Ans. Split A, 247 sq. in.; split B, 480 sq. in.; split D, 1491 sq. in.

65. Taking the width of the airway (8⅓ feet) as 100 inches,

what will be the respective widths of the openings at the mouths of the several splits, in problem 63?

Ans. Split A, 3.38 in.; split B, 13.75 in.; split C, 43.37 in.; split D, 39.50 in.

66. Suppose a vein dipping at an angle of 30 degrees to be ventilated in two main splits. The headings or levels are 400 feet apart, measured upon the slope; the size of the dip-split is 6 × 8½ feet and 10,000 feet long; temperature of the intake 50° F. and of the return 70° F., barometer 30 inches. The regulators are arranged so that the dip-split takes 20,000 cubic feet of air per minute, while the level-split takes 30,000 cubic feet. How much air per minute will each split take when the total quantity of air furnished per minute to the mine has been reduced to 40,000 cubic feet, supposing that no change is made in the regulators?

Ans. Level-split, 23,555 cu. ft.; dip-split, 16,445 cu. ft.

67. In the last problem, what quantities of air per minute would each split take were the circulation to be increased from 50,000 to 60,000 cubic feet per minute?

Ans. Level-split, 36,444 cu. ft.; dip-split, 23,556 cu. ft.

GENERAL PROBLEMS.

68. Suppose we have a current of 50,000 cubic feet of air per minute travelling in two splits; size of airways 6 × 8½ feet and the entire length 30,000 feet; if a fall occur upon the main airway before the split is reached, so as to reduce the sectional area of the same from 50 to 25 square feet, the power of the motor remaining the same, what quantity of air per minute will pass over the fall and through the mine, assuming a temperature of 60° F. and a barometer of 30 inches?

Ans. 49,437 cu. ft.

69. In a certain mine a current of 50,000 cubic feet per minute is passing in two splits of the following size:

Split A. 6 × 8½ ft., 10,000 ft. long.
" B. 6 × 10 " 40,000 " "

If we now introduce a box-regulator having an opening of 60.56 square inches, into split A, what quantity of air will then pass in each split per minute, assuming that the power is increased to maintain the flow of 50,000 cubic feet in the main intake, temperature 60° F., and barometer 30 inches?

Ans. Split A, 10,000 cu. ft.; split B, 40,000 cu. ft.

70. In the last problem, what per cent of the power is lost in the regulator; give also the horse-power of the circulation in the two methods?

Ans. 49.66%; old method, 446.828 h.p.; new method, 224.922 h.p.

71. If a certain motor is capable of circulating a current of 20,000 cubic feet per minute through a certain mine, and another motor 30,000 cubic feet per minute in the same mine, each working alone but under like conditions, what quantity of air per minute will result from their combined action under the same conditions? (See equation XXXIII.)

Ans. 32,711 cu. ft.

72. If the motor first mentioned above, in performing its work of circulating 20,000 cubic feet of air per minute through a certain mine, yields a water-gauge of 2 inches, the water-gauge yielded by the second motor in the circulation of the 30,000 cubic feet of air per minute will be $4\frac{1}{2}$ inches; what will be the water-gauge when the two motors are working together under the same conditions?

Ans. 5.35 ins.

ADDENDA.

We will consider here such other conditions prevailing in the pit as affect to a greater or less degree the ventilation of the same, but which are ignored in our ordinary calculations. These are interesting, however, as matters of information, and are quite essential in all cases of careful investigation. We refer now to the change in the weight of the downcast column, due to the pressure of the pit, in compressive ventilation; and to the variation in the weight of the upcast column, arising from the saturation of the return current. Also such other cases will be here introduced and other formulas developed as require to some extent a knowledge of the higher mathematics. These have been eliminated from the main body of the book, because they are not essential to a practical knowledge of the subject; but the work would not be complete without reference to them.

Condition of Current due to Pressure and Saturation.—There are three conditions of the air in the pit, and the weight of this air is therefore represented by three different expressions, as follows:

Exhaustive downcast:

$$\mathrm{w}_2 = \frac{1.3253B}{459+t_2}. \qquad \text{(1)}$$

Compressive downcast:

$$w_2 = \frac{93.7B+p+h(\mathrm{w}_1-\mathrm{w}_2)}{70.7(459+t_2)}. \qquad \text{(2)}$$

Upcast (2 cases):

$$\mathrm{w}_1 = \frac{1.4396(B-\phi_{t_4})+0.8263\phi_{t_4}}{459+t_1}. \qquad \text{(3)}$$

In the case of the upcast column two conditions may arise. First, as in the case of a dry furnace-shaft, the temperature t_4, at which the air was saturated, is lower than the temperature t_1, the average temperature of the upcast. Second, as in the case of a wet furnace-shaft, or any case of fan-ventilation or otherwise, where the upcast column is not heated, the temperature (t_4) at which the air is saturated will be equal to the temperature of the shaft, the excess of moisture being deposited all the way up the shaft, as the current is cooled in its ascent. The average temperature of saturation will then be identical with the average temperature of the shaft. The temperature of saturation can never be greater than the temperature of the shaft, as the moisture would then be at once deposited.

The above three expressions are developed as follows: Expression (1) is a simple case, and gives the weight of one cubic foot of dry downcast air under the barometric pressure B, and the average temperature of the downcast shaft t_2; it is derived from equation (I). This expression is applicable only to the exhaustive system, where natural draft, furnace, or exhaust-fan is in use.

Expression (2) applies to the compressive system of ventilation, and gives the weight of one cubic foot of dry, downcast air, subject to the barometric pressure B and the theoretical unit of ventilating pressure p, due to the resistance of the rubbing surface of the airways, and expressed by equation (XXIII), and a further back-pressure, arising from the vitiated condition of the upcast current. This unit of back-pressure, due to the heaviness of the upcast current, is readily found by deducting the weight of one cubic foot of air, as given by expression (1), from the weight of one cubic foot of air derived from expression (3); and multiplying the excess or difference thus found by the motive height h, which will give the unit of back-pressure from this cause very approximately. Now, equation (1) gives the weight of one cubic foot of air under the barometric pressure B, which pressure is expressed in inches of mercury; hence, in the present instance, we must reduce the unit of ventilating-pressure p, and the unit of back-pressure $h(w_1 - w_2)$ to inches of mercury, and add these results to the B of equation (1). We see by referring to equation (XXXVI)

that one inch of water-gauge represents a unit of pressure of 5.2 pounds; and since the specific gravity of mercury is 13.596, it follows that one inch of mercury represents a unit of pressure of 70.7 pounds. Hence, dividing these units of pressure by 70.7, and adding the results to B, and substituting for B in equation (1), and reducing, we obtain expression (2).

Expression (3) gives the weight of one cubic foot of the vitiated upcast current, and is obtained by adding together the following expressions (see equations (1), (3), (5), (XLIV)):

$$\text{(Nitrogen, 1 cu. ft. upcast).} \quad \frac{1.0205(B - \phi_{t_4})}{459+t_1}. \quad . \quad (4)$$

$$\text{(Carb. acid, 1 cu. ft. upcast).} \quad \frac{0.4191(B - \phi_{t_4})}{459+t_1}. \quad . \quad (5)$$

$$\text{(Aq. vapor, 1 cu. ft. upcast).} \quad \frac{0.8263\phi_{t_4}}{459+t_1}. \quad . \quad . \quad . \quad (6)$$

Box-regulators.—There has always been experienced some difficulty in estimating exactly the influence which these regulators exert upon the current of air, and in figuring the size of opening in such a regulator which will give the required amount of air in each of the splits in question. As a matter of fact in practice, we set up the regulator and move the shutter to and fro, until the desired proportion of air is obtained; and this practice is correct, as the varying conditions of the air-courses are constantly introducing factors which modify the results. Nevertheless, it is interesting to investigate the principles which control the flow of the air-current through the opening.

To begin with, we recognize that this form of regulator is introduced into that one of two splits which is taking more air than the desired proportion, in order to obstruct the flow in that split. The obstruction thus introduced creates an increase of pressure behind the regulator, which *increase* is due to the regulator alone, as distinct from the mine-pressure at this point, or the pressure incident to the flow of the current ahead of the regulator. We note that the pressure due to the regulator is unbalanced by anything on the other side; it is, in other

words, the pressure which animates the flow through the opening of the regulator, or it is the pressure which will take the current through this opening. It will not do any more; it does not contribute to the movement of this current ahead of the regulator; the mine-pressure does that; it simply overcomes the regulator, and places the current ahead of the regulator under the same conditions as would exist were the regulator not there. We will first find what this pressure due to the regulator is, in terms of the quantity of air passing through the opening and the size of the opening (we are speaking now of the pressure per square foot, or the *unit* of pressure). Having found this *unit* of pressure (p) due to the regulator, we will multiply it by the sectional area of the airway to obtain the *total* pressure due to the regulator, and then again multiply this result by the velocity of the current, which will give the *work* absorbed or lost in the passage of the regulator; or, we may multiply at once by the quantity of air passing per minute, and obtain the same result.

Pressure due to Box-regulator.—The flow of a current of air through the opening in a box-regulator is identical with the flow of any fluid through an orifice in a thin plate; and, as we have seen in Chapter X, the velocity of the flow is represented by the equation,

$$v = \sqrt{2gh}, \quad \dots \dots \dots \quad (1)$$

from which we have,

$$h = \frac{v^2}{2g}, \quad \dots \dots \dots \quad (2)$$

in which v is the velocity of the flow through the orifice in feet per second. Hence we have for the quantity of the flow per minute Q, through the orifice or opening $a_{,,}$,

$$Q = 60a_{,,}v, \quad \dots \dots \dots \quad (3)$$

from which we may write,

$$v^2 = \frac{Q^2}{3600a_{,,}^2}. \quad \dots \dots \dots \quad (4)$$

But in all cases of the flow of a fluid through an opening in a thin plate there results a contraction of the area of the flow

just outside of the orifice, which reduces the quantity of the flow. This contraction of area is known in physics as the *vena contracta*, and varies according to the form of the orifice, and in our case, where the orifice or opening is within an airway, and bears a considerable relation to the sectional area of such airway, the contraction of area will vary according to the size of the opening, relative to the sectional area of the airway; thus the contraction will diminish as the area of the opening approaches that of the airway, and *vice versa*. The coefficient of this contraction may, therefore, be represented very approximately for our purpose by the seventh root of the ratio expressed by dividing the area of the opening by the area of the airway, or by the expression

$$\sqrt[7]{\frac{a_{\prime\prime}}{a}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Hence, the true area of the flow will be represented by the expression,

$$\sqrt[7]{\frac{a_{\prime\prime}}{a}}a_{\prime\prime} \quad \text{or} \quad \sqrt[7]{\frac{a_{\prime\prime}^{8}}{a}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Squaring this expression, and substituting it for $a_{\prime\prime}^2$ in equation (4), we have,

$$v^2 = \frac{Q^2}{3600}\sqrt[7]{\frac{a^2}{a_{\prime\prime}^{16}}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Now h in equation (2) is the generative height; it is the height of the surface of the fluid above the orifice (see Fig. XIII.), it is the head of air-column. Hence, referring to equation II., and substituting this value for h in equation (2) above, and substituting for v in the same equation its value as taken from equation (7) above, solving with respect to p, and reducing, we have for the unit of pressure due to the regulator,

$$p = 0.00000572\frac{B}{459+t}\sqrt[7]{\frac{a^{23}}{a_{\prime\prime}^{16}}}Q^2. \quad . \quad . \quad . \quad \text{(LXV)}$$

Work due to Box-regulator.—To find the work absorbed or lost in the passage of this form of regulator, we multiply the

above unit of pressure (p) due to the regulator by the quantity of air (Q) passing per minute and we have

$$u = 0.00000572\frac{B}{459 + t}\sqrt[7]{\frac{a^2}{a_{\prime\prime}^{16}}Q^8}. \quad . \quad . \quad \text{(LXVI)}$$

Illustration.—Suppose now that we have in a certain mine a current of 10,000 cubic feet per minute travelling in two splits as follows:

Split A. 6 × 8½, 5000 ft. long.
" B. " 8000 " "

If no regulator is introduced the natural division of the air would send 5391 cubic feet into split A and 4609 cubic feet into split B. Now suppose we desire to throw 6000 cubic feet of this current into split B, what size of opening in a box-regulator introduced into split A will accomplish this result? We have seen in Chapter IX that the unit of work pv at the point of split or the work transmitted by one square foot of sectional area to each of the several splits is the same, reacting against each other, and as the exposed areas of the two splits in this case are the same, the total work performed in each must be the same. Now we ascertain from equation (XIII) the work that will be consumed in circulating 6000 cubic feet of air per minute through split B, and this work (8600 foot-pounds) will be also the work applied to split A, that is to say, the work that is responsible for the circulation of 4000 cubic feet of air in this split per minute plus the work lost in the passage of the regulator. Finding from equation (XIII) the work absorbed in this split by the circulation of the 4000 cubic feet of air (1592 foot-pounds) and deducting this from the total work applied (8600 foot-pounds) we obtain 7008 foot-pounds as the work absorbed by the regulator. Finally, substituting this value for u in equation (LXVI), and assuming a temperature of 60° F. and a barometric pressure of 30 inches, giving to a and Q their numerical values and reducing, we obtain for the value of $a_{\prime\prime}$,

$$a_{\prime\prime} = 380 \text{ sq. ins.},$$

or an opening of 19½ inches square. This problem, as well as many others of this nature, is very easily worked by the aid of

logarithms, but on account of the high powers of some of the quantities can only be approximated by the methods of arithmetic. We would recommend the use of logarithms in the solution of all problems in mine ventilation.

Quantity of Air passing a Box-regulator.—We may write for the work performed in each split as follows:

$$\text{Work in split A.} \left(0.00000572\frac{B}{459+t}\sqrt[7]{\frac{a^2}{a_{\prime\prime}^{16}}}+\frac{ks}{a^3}\right)Q^3.$$

$$\text{Work in split B.} \frac{ks_\prime}{a_\prime^3}Q_\prime^3.$$

Then, equating these works and solving with respect to Q, the quantity of air passing the regulator per minute, and writing the potential X for its value (see equation (XXVII)), we have,

$$Q=\frac{Q_\prime}{X_\prime\sqrt[3]{0.00000572\frac{B}{459+t}\sqrt[7]{\frac{a^2}{a_{\prime\prime}^{16}}}+\frac{1}{X^3}}} \qquad \text{(LXVII)}$$

Effect of Fall upon Main Air-course.—When a fall occurs upon the main air-course so as to seriously obstruct the flow of the air-current the amount of the flow after the fall may be figured from equation (LXVII), by $Q_\prime$ represent the quantity of air passing in the airway before the fall occurred, and $a_{\prime\prime}$, the reduced sectional area of the airway at the fall; in this case $X_\prime$ will be equal to X.

Effect of Inclination or Curvature of Blade of a Fan.—In all fans having inclined or curved blades, the reaction of the air against the blade being normal to the blade is no longer tangential to the rotary motion of the fan, and as a consequence there results a loss in the accelerative velocity imparted to the air by virtue of its revolution in the fan.

Let us for a moment suppose the air contained in one section of a fan to be concentrated at the point a upon the path of its centre of gravity. Now, the point a is impelled or moved forward by the motion of the blade in the direction ab tangential to the rotary path of the blade, and the force which

impels it is the velocity with which the blade is moving, but the direction of this motion or of the impelling force *ab* not being normal to the surface of the blade at this point, there results a sliding (*ac*) of the point along the surface of the blade, and the resultant of these two motions is *ad*; consequently the point *a* has been moved outward in a radial direction, or normal to the tangent *ab*, a distance (*ed*). Now, inasmuch as the power of the fan is derived from the centrifugal force incident to the revolution of the weight of air which we have considered as concentrated at its centre of gravity *a*, and inasmuch as this

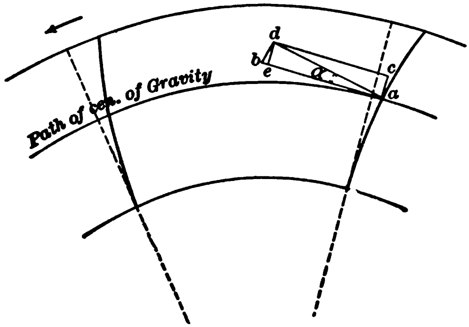


FIG. XVII.

centrifugal force is dependent for its development upon the retention of the point *a* in the rotary path, any movement or yielding in a radial direction, due to mechanical influence, will result directly in a loss to the centrifugal force, as expressed by the equation (3–XXXVIII); it will be readily noted that while this movement in a radial direction reduces the acceleration due to the centrifugal force and therefore the measure of this force (*fm*), it does not reduce the distance through which this force acts; it only makes a part of such distance due to the mechanical influence of the inclined blade.

Now, referring again to Fig. (XVII), we see that for any infinitesimal period of time the tangent *ab* will correspond to and form a part of the circle described by the point *a*, and will therefore represent the space passed over by this point in such

infinitesimal time. Denoting this space by v, we may write from the figure

$$ed = v \sin \alpha \cos \alpha, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

ed representing, as we have seen, the loss to the accelerative velocity for an infinitesimal period of time.

Referring to equation (6–XXXVIII), and dividing by two, to obtain the space passed over by the air considered as concentrated at the point a under the accelerative influence in one second of time, we have the expression

$$0.005483Rn^2, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and for the infinitesimal period of time referred to above we have,

$$\frac{60v}{2\pi Rn}(0.005483Rn^2), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

or, reducing, we have,

$$0.052359vn. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

This last expression represents the space passed over by the air considered as concentrated at the point a under the accelerative influence of a straight-paddle blade in the same infinitesimal period of time.

Then, finally, by dividing expression (1) by expression (4) we obtain the ratio expressing the loss to the accelerative velocity and consequently to the centrifugal force.

$$19.1\frac{\sin \alpha \cos \alpha}{n}. \quad . \quad . \quad . \quad . \quad (\text{LXVIII})$$

This expression (LXVIII) represents the ratio by which the centrifugal force of the revolved air is weakened, and by which also the power of the fan is impoverished. Any particle of air, as a, for example, in its passage through the fan moves under the influence of two forces; one of these forces (the mechanical revolution of the fan) impels it in a direction normal to the surface of the blade; the other (the centrifugal force) is a radial

force; as a result of the combined action of these two forces, the particle moves in a spiral path, revolving with the fan-blades, but ever approaching the outer circumference, where it is thrown off. The radius of curvature of this spiral will be greater, and consequently the centrifugal force developed by the revolution will be less, as the fan-blade is more inclined.

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